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THE EFFECT OF CERTAIN IMPURITIES ON THE SPECTRA OF SOME GASES.

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It has frequently been observed that under certain conditions small traces of a foreign substance in a gas may affect the spectrum of the latter to an unexpected extent. Heretofore little systematic investigation of such phenomena has been made, and it was thought that it might be of interest to examine the interactions of some substances which are rarely or never absent from vacuum tubes, namely, mercury vapor, hydrogen, oxygen, and water vapor. The following cases have been studied:

1. *The spectrum of hydrogen.*—(*a*) Pure; (*b*) containing traces of mercury vapor; (*c*) containing traces of oxygen; (*d*) containing traces of water vapor.

2. *The spectrum of oxygen.*—(*a*) Pure; (*b*) containing hydrogen; (*c*) containing mercury vapor.

The method of investigation was first to observe the spectrum of the gas in as pure a condition as possible, particularly with respect to the substances whose influence was to be studied. It was impracticable to note all details, but the general appearance of the spectrum was observed, and photometric measure-

ments of the luminosity of selected parts or lines made, at various pressures of the gas. Small quantities of the foreign substances were then introduced and the observations repeated.

In order to guard against disturbances due to the absorption or giving off of gases by internal metallic electrodes, external electrodes, such as those described by Salet,[1] were used. For this reason no measurements of current strength were practicable.

THE APPARATUS.

The general arrangement of the apparatus is shown in Fig. 1. Hydrogen is generated in the voltameter *V* from distilled water containing a small quantity of phosphoric acid. The traces of oxygen always present in hydrogen generated in this manner were removed by passing through a strong solution of pyrogallic acid in the vessel *A*. The gas is stored in the drying tubes *C*, containing respectively calcium chloride, solid potassium hydroxide, and phosphorus pentoxide. *G* is a sulphuric acid valve to exclude mercury vapor coming from the pump, and *F* is a tube containing solid potassium hydroxide to absorb the vapors coming from the sulphuric acid. The vacuum tube *D* is of the H-shaped end-on type. The electrodes are made of four pieces of brass tubing separated from the glass by mica. Without this precaution the tubes were invariably sparked through, owing to the high potentials used. The capillary part of the tubes generally used was about 10 cm long and 4 mm internal diameter. *E* is a reservoir containing mercury, which, by opening a cock, may be admitted into the discharge tube at a pressure corresponding to the temperature of the reservoir, which was always lower than that of the vacuum tube. *B* is a glass bulb containing potassium permanganate from which oxygen may be generated by heat.

At first all parts of the apparatus were fused together. This gave rise to inconvenience on account of frequent change or renewal of parts of the system, and finally several sealing-wax joints were used. No injurious effects were noticed unless

[1]SALET, *Ann. Chim. et Phys.*, **28**, 20, 1873.

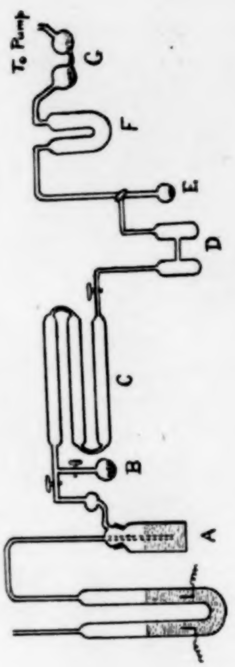


Fig 1

the discharge reached the joints, when carbon monoxide bands always appeared. The same was found to be true of stopcocks, which were avoided at first on account of the grease, the gas under investigation being introduced through a barometer tube. In studying the effects of mercury vapor this method was of course impracticable, and stopcocks were necessary. At low pressures the carbon monoxide bands always appeared after the discharge had passed for several minutes. In these experiments, however, the discharge tube was always connected with the pump, and observations were made on fresh gas which had not had time to become contaminated by vapor from the cocks. The diffusion of the vapor was also hindered by capillary contraction in the tubing between the discharge tube and the cocks.

A small induction coil was used which, under the usual conditions, gave a spark of some 5 cm length. It was fed by a current from the city leads, at a potential of 110 volts, through a Wehnelt interrupter. The tube with external electrodes is practically a condenser, and it was found that the interrupter would not work so easily and uniformly as with a closed secondary circuit. Furthermore, it was impossible to always maintain constant conditions, owing to frequent renewal of the interrupter, change in the concentration of its acid solution, etc. During a given series of experiments, however, the conditions usually varied little, and different series have been as nearly as possible reduced to the same scale by assuming that in a pure gas at a given pressure in a given tube, the luminosity is proportional to the current strength.[1]

Photometric measurements were made with a Glan spectrophotometer, with an ordinary glowlamp, behind a screen of oiled paper, as a standard. As relative values only were required, the luminous intensity was taken as equal to the square of the tangent of the angle read multiplied by a convenient constant factor.

[1] FERRY, *Phys. Review*, **7**, 9, 1898.

RESULTS.

I. *Hydrogen.*—The first experiments were made for the purpose of determining the relation between luminosity and pressure in the case of pure hydrogen. The luminosity is also a function of the current strength, which in these experiments was unknown; but the source of the current supply was kept as constant as possible, so that the results are comparable.

Measurements were usually made on fresh hydrogen, so that in all probability the results are very little affected by the presence of carbon compounds or gases given off by the glass. In some cases observations were repeated on the same portion of hydrogen, with its pressure reduced by pumping out. Usually such readings (indicated by the sign [–] in the table of results) were a little smaller than those made on fresh hydrogen.

For the sake of more accurate photometric measurements, a slit of about 5 mm width was used. For this reason, the compound spectrum of hydrogen, which was invariably present, appeared as a group of wide bands in the red and orange, and as a continuous spectrum in the green. Photometric measurements were made on $H\alpha$ ($\lambda=6563$), $H\beta$ ($\lambda=4861$), and the compound spectrum in the neighborhood of the green mercury line ($\lambda=5460$). Only a few observations were made on $H\beta$, as its luminosity seemed to follow the same law as $H\alpha$, and measurements in this part of the spectrum are difficult. The results are given on page 142.

These results for $H\alpha$ and $H\beta$ are plotted in the curves (I. $H\alpha$) and (I. $H\beta$), and for the compound spectrum in the upper sinuous curve (I. H^{II}) of Fig. 2. They show that, keeping the conditions of current supply constant, the luminosity of both the elementary and the compound spectrum of pure hydrogen reaches a maximum at about 3 mm pressure, and then diminishes very rapidly with the pressure. With increasing pressure the elementary spectrum diminishes in luminosity faster than the compound, and at pressures of more than 4 or 5 cm the latter alone remains visible, although too feeble to be measured. When these experiments were repeated with a tube having internal electrodes, the

I.

Pressure	Luminosity		Pressure	Luminosity	
	$H\alpha$	Compound		$H\alpha$	Compound
0.7	33	4.5	—11.8	24	6.2
0.7	35	4.9	12.5	18	6.2
—0.8	33	4.0	15	17	4.5
1	44	4.5	15	16	4.5
1.4	65	8.8	—16	13	4
1.3	70	7.3	—23.5	4	2.8
—1.5	55	8	—28	3	2.5
1.5	65	9.4	—27	3	2
1.7	81	12.6	—36	2.5	1
—1.8	65	8.8	42	1	2
—2.3	78	8.8			
2.6	96	12.8			
3	107	13		$H\beta$	
3.2	103	12			
3.9	93	9.4			
—4.2	90	12	0.9	52	
—4.5	81	8.8	1.5	100	
5.5	73	9	2.6	106	
5.8	70	8.8	3.5	86	
8	63	8	4.5	92	
—9	45	8.8	11	42	

luminosity increased down to the lowest pressures obtainable with the sulphuric acid valve (about 0.6 mm). Lagarde,[1] using interna electrodes, found that with a current of 115×10^{-6} amperes there was no change in the luminosity of $H\alpha$, $H\beta$, and $H\delta$ with the density between 1.8 and 0.27 mm pressure. With smaller currents the luminosity diminished, with greater currents it increased, as the pressure was reduced from 1.8 to 0.27 mm. Ferry[2] found a continuous increase in luminosity of $H\alpha$ and the compound spectrum as the pressure diminished down to 0.7 mm, with internal electrodes and currents ranging from 1 to 6 mm. The point of maximum luminosity is therefore a function of the current strength as well as the density, and no conclusion can be drawn regarding the differences between tubes with internal and those with external electrodes without a knowledge of the current strength in the former. From the general conditions and appearance of the discharge,

[1] LAGARDE, *Ann. de Chim. et Phys.*, **4**, 352, 1881.

[2] *Phys. Review*, **7**, 6, 1898.

it would hardly seem possible that the current strength diminishes as rapidly as the luminosity below 30 mm pressure.

These results are of course functions of the current density rather than of current strength, and may vary greatly with the size of the tube. With a very wide capillary (1 cm in diameter) only the compound spectrum appeared, and with increasing current, or smaller capillary, the line spectrum increases in luminosity more rapidly than the compound. Although the latter was never absent, it was weaker when traces of mercury vapor, oxygen, or water vapor were present. This point will be discussed later.

THE EFFECT OF TRACES OF MERCURY VAPOR ON THE HYDROGEN SPECTRUM.

Mercury vapor from the pump was kept out by the sulphuric acid valve, but it was exceedingly difficult before beginning a series of observations to get rid of the last traces of mercury vapor carried into the system with the air from the room. The green line ($\lambda = 5460$) persisted after the tube had been repeatedly heated, pumped out, and filled with fresh hydrogen. Even when all mercury had apparently been removed, the green line would slowly reappear in the spectrum after the discharge had passed for some minutes or on heating the tube. It usually required a day or more of steady work to remove all traces of the mercury spectrum, and it was necessary to repeat this process every time after air had been admitted into the tube. It seems inconceiv able that mercury vapor should have remained persistently in the tube under such conditions. It is probable that a film of mercuric oxide had been deposited on the glass, which was gradually decom posed by heat or by the discharge. Like results were noted in later experiments with oxygen, in which mercuric oxide was certainly present. Several times, also, the green line flashed out brightly when the discharge first passed, and then faded away, as though the mercury vapor had been torn from combination, and gradually dissipated by diffusion.

These facts indicate a persistency and spectral sensitiveness

on the part of mercury vapor of which little mention has been made in the literature of the subject, and which seems worthy of closer investigation. Plücker and Hittorff[1] note the remarkable spectral sensitiveness of mercury vapor, but many other investigators have seemed to consider its effects negligible. Hertz,[2] after showing how small the saturated vapor pressure of mercury vapor at ordinary temperatures is, says: "The smallness of this pressure, and not any characteristic property of mercury, may be considered the cause of the minute effect which the ever present mercury vapor has on the discharge phenomena in Geissler tubes."

In many cases tubes filled with sulphur to absorb the mercury vapor, and with copper turnings to absorb the sulphur vapor, are interposed between the pump and the discharge tube, but little has been written concerning the effectiveness of this arrangement. Ames,[3] who used such tubes, found some mercury lines on his photographic plates. Warburg[4] found that this method did not completely exclude mercury vapor. In the foregoing series of experiments it was found that this arrangement eliminated some mercury lines, and noticeably weakened the green line, but it was never entirely absent from the hydrogen spectrum without the use of the sulphuric acid valve.

E. Wiedemann[5] studied the spectra of mixtures of air and of hydrogen with saturated mercury vapor between ordinary temperatures and about 240°. No photometric measurements were made by him, but he showed that in each case the mercury spectrum rapidly grew brighter, while the spectrum of the hydrogen or nitrogen grew weaker and finally disappeared at very high temperature. On cooling the tube the reverse phenomena were observed.

[1] PLÜCKER and HITTORFF, *Phil. Trans.*, **155**, 25, 1865.

[2] HERTZ, *Wied. Ann.*, **17**, 200, 1882.

[3] AMES, *Phil. Mag.*, **30**, 49, 1890.

[4] WARBURG, *Wied. Ann.*, **31**, 576, 1887.

[5] E. WIEDEMANN, *Wied. Ann.*, **5**, 517, 1878.

Koch[1] found that the mercury lines completely disappeared from the spectra of hydrogen, oxygen, and nitrogen when the vacuum tube was cooled down to -80°.

It was decided to study the effect of mercury vapor upon the hydrogen spectrum at ordinary temperatures, and the relation between luminosity and vapor density of the mercury vapor, and to determine the minimum quantity of the latter necessary, under the conditions, to produce luminosity. The yellow and blue lines of mercury became visible only when the reservoir E (Fig. 1) was nearly at room temperature, the highest reached in these experiments, so measurements were taken on the green line alone.

After making observations on pure hydrogen, the reservoir E (Fig. 1), containing mercury and kept at a constant low temperature by a freezing mixture, was placed in communication with the discharge tube, and the relative intensities of $H\alpha$ and the green mercury line measured, after allowing time for the diffusion of the mercury vapor. The luminosity of the mercury line reached a maximum within a few minutes, which is rather surprising considering that the vapor had to traverse about half a meter of tubing averaging about 6 mm in diameter. Measurements were repeated with different pressures of hydrogen, and with the reservoir E at different temperatures. The first measurements made when E was at temperatures below 0° were irregular and unsatisfactory. This was partly due to the great difficulty in measuring the very feeble intensity of the green line under these conditions; partly, perhaps, to traces of mercuric oxide still remaining in the tube. The principal difficulty, however, came from the method of estimating the intensity of the background formed by the hydrogen spectrum. With a wide slit and fresh hydrogen this was practically uniform and continuous in this region, and the true intensity of the mercury line was assumed to be the difference between its apparent intensity and that of adjacent parts of the compound hydrogen spectrum. It was observed, however, that at low pressures, after the discharge had passed for a few minutes, several faint and diffuse

[1] KOCH, *Wied. Ann.*, **38**, 216, 1889.

green lines appeared in the neighborhood. Careful investigation with mercury vapor excluded led to the discovery of another line resembling these in all respects and almost exactly coincident with the mercury line. All these lines were found to vary exactly alike in intensity, so in future observations the intensity of the mercury line was taken as the difference between its apparent intensity and that of the nearest of these foreign lines. These lines apparently did not belong to the hydrogen spectrum, as they, with the mercury line, disappeared when a slow stream of pure hydrogen flowed through the tube. They also appeared in a tube with internal electrodes and in one filled with nitrogen. They disappeared with pressure exceeding 4 or 5 mm and when much mercury vapor was present.

Estimates of the luminosity of the mercury line made in this manner were uniform and consistent. With the reservoir E below -5°, however, it was too feeble for measurement. At -20° it was barely perceptible to the eye, and at -40° had vanished completely. These limits would, of course, be changed by using a capillary discharge tube of a different diameter or a different current.

At high pressures of hydrogen, the mercury line changes very slowly in intensity, and when the reservoir E is at a temperature of 10° or above it remains visible up to pressures of 10 cm or more, when only the exceedingly faint compound spectrum of hydrogen can be seen.

Measurements were made of the intensities of $H\alpha$, the green mercury line, and the neighboring foreign line (or the adjacent compound hydrogen spectrum when the latter did not appear) while the mercury reservoir was at temperatures of -5°, $+3^\circ$, $+7^\circ$, $+11^\circ$, and $+21^\circ$, and in communication with the vacuum tube. The vapor pressure of the mercury in the latter was equal to the saturation pressure of the mercury in the reservoir. These pressures were calculated from Hertz's formula[1]

$$\log p = 10.59271 - 0.847 \log T - \frac{3342}{T}.$$

[1] HERTZ, *Wied. Ann.*, 17, 199, 1882.

Usually the readings were taken after the introduction of fresh hydrogen (allowing sufficient time for diffusion of the mercury vapor), but sometimes observations were repeated on the same gas, pumped out to lower pressures. Such results are indicated by the sign — in the tables given below. Many similar observations were made at various times, with the same qualitative results, but those given below were made immediately after those on pure hydrogen previously given. At the end observations were repeated on pure hydrogen, which showed that the conditions had remained unchanged, and that the results are comparable.

The lower sinuous curve (VI.H″) represents the luminosity of the compound spectrum, with the mercury reservoir at 21°.

An independent set of readings was made on $H\beta$, at another time, and is given in Table VII (compare with Table I).

With the mercury at $-5°$ and $3°$ the luminosity of $H\alpha$ is almost precisely the same as with no mercury vapor present. With the mercury at 7°, there is a slight diminution in the luminosity of $H\alpha$, which becomes more marked with the mercury at 11° and 21°. $H\beta$ also has its luminosity greatly diminished by the presence of mercury vapor (compare with Table I). The luminosity of $H\alpha$ still has a maximum at a pressure of about 3 mm (possibly at a slightly greater pressure when considerable mercury vapor is present). The luminosity of the mercury vapor begins to increase very rapidly with diminishing pressure at about the point where $H\alpha$ begins to grow weaker. The compound spectrum fluctuates somewhat irregularly (as seen by comparing Table IV with the others), but in the main follows the same laws as $H\alpha$.

The effect of mercury vapor on the luminosity of hydrogen is shown very strikingly in Table VIII. After the admission of fresh hydrogen the luminosity of $H\alpha$ and of the compound spectrum faded gradually as mercury vapor diffused over from the reservoir at 20°, and grew brighter when the reservoir was cooled.

	Pressure	Intensity			
		Ha	Foreign line + compound spectrum	*Hg.* app.	*Hg.* corr.
II. Temperature of mercury, —5°. Vapor pressure 0.000116 mm.	0.7	39	8.3	11.8	3.5
	1.8	65	8.8	10	1.2
	2.7	78	7.8	8.3	0.5
III. Temperature of mercury +3°. Vapor pressure, 0.000220 mm.	— 0.7	36	5.3	12.6	7.3
	— 1	41	7.3	13.3	6
	1.8	69	9.4	11.2	1.8
	— 4	61	7.3	10	2.7
	9	36	3.6	4.9	1.3
IV. Temperature of mercury 7°. Vapor pressure, 0.000340 mm.	0.9	33	2.5	10.6	8.3
	1.2	34	2.8	8.2	5.4
	3.6	90	5	8.8	3.8
	— 4.4	68	5.3	8.8	3.5
	5	70	5	10	5
	10	33	5.3	7.8	2.5
	13	16	3.6	6.7	3.1
	22	4	2.5	4.5	2
	31	1.5	1.5	3	1.5
	44	0	1.5	2.5	1
			Compound Spectrum	Foreign lines no longer visible	
V. Temperature of mercury 11°. Vapor pressure, 0.000530 mm.	— 0.8	19	3.3	14.8	11.5
	1.9	53	10.6	15.5	4.9
	2.5	57	10	13.3	3.3
	— 2.7	4.9	6.2	10.6	4.4
	3.2	61	8.3	11.9	3.6
	— 4	51	8.2	11.2	3
	— 4.5	57	10	13.3	3.3
	9	26	5.3	7.8	2.5
	26	3.3	1.5	3.6	2.1
	34	1	0.8	2.8	2
VI. Temperature of mercury 21°. Vapor pressure, 0.001350 mm.	— 0.6	16	2.5	30.7	28.2
	1.1	38	4.2	32	27.8
	— 1.5	34	6.2	31	25
	— 2.6	39	7	23.8	16.8
	— 2.7	36	5.7	19	13.3
	4	33	7	23.8	16.8
	— 5.8	37	7.3	17	9.7
	6.5	33	7.3	14.8	7.5
	—14	13	4.9	10.6	5.7
	19	7	3.9	9.3	5.4
	21	6	3.6	8.2	4.6
	36	1	1.1	3.3	2.2

These results are shown graphically in Fig. 2, and are numbered to correspond with the above ables.

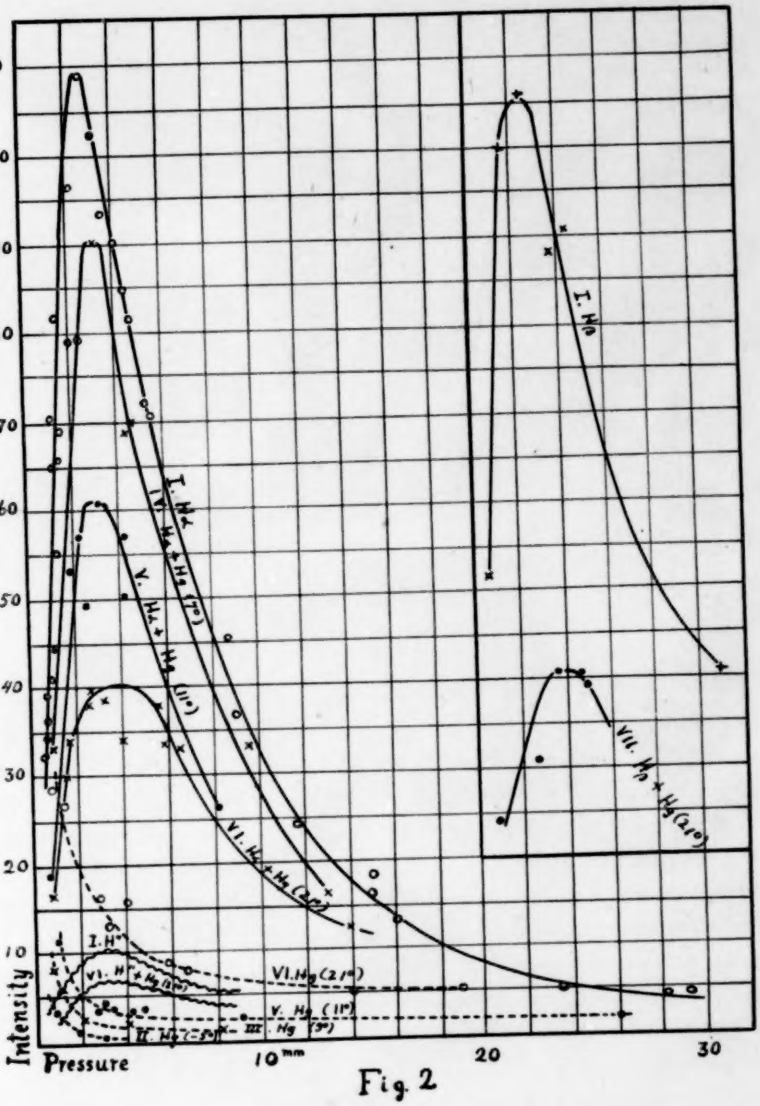

110
100
90
80
70
60
50
40
30
20
10
Intensity
Pressure
10mm
20
30
I. Hα
IV. Hα + Hg (7°)
V. Hα + Hg (11°)
VI. Hα + Hg (21°)
I. Hβ
VII. Hβ + Hg (22°)
I. H
VI. H + Hg (11°)
VI. Hg (21°)
V. Hg (11°)
III. Hg (9°)
II. Hg (-5°)

Fig. 2

VII.

MERCURY AT 21°. VAPOR PRESSURE 0.001350 MM.

Pressure	$H\beta$	Compound spectrum	*Hg* app.	*Hg* corr.
1	24	8	20	11.3
2.5	31	5	17	8.7
3.5	42	10	20	10.1
4.5	39	11	16	4.6

VIII.

Pressure	$H\alpha$	Compound	*Hg* app.	*Hg* corr.	Remarks
0.9	36	4.5	0	0	Fresh hydrogen
	15	2.5	18	15.5	*Hg* at 20°
	28	6	11	5	*Hg* at 3°
1.1	59	13	0	0	Fresh hydrogen
	38	4.2	32	27.8	*Hg* at 21°
	63	12.5	19.8	7.3	*Hg* at 5°
4	100	12	0	0	Fresh hydrogen
	33	7	23	16.8	*Hg* at 21°
6.5	59	11	0	0	Fresh hydrogen
	33	7.3	14.8	7.5	*Hg* at 21°

The first and second sets of readings were obtained on different days and under different conditions, and are not comparable in absolute values.

Several times when the tube contained mercury vapor it was heated strongly with a Bunsen flame. No change of luminosity of either the hydrogen or the mercury spectrum was observed. Little change in density of either gas could be caused by the rise in temperature, as the tube was closed by cocks near each end. It would appear that, within this range of temperatures, the relation between the intensities of the two spectra is a function of the relative quantities of the two gases present, not of the temperature.

Although the luminosity of mercury reaches no maximum, the relative densities and relative luminosities of mercury and $H\alpha$ are nearly proportional for all pressures of hydrogen less

than 6 mm, as shown by the following table. K is a constant of proportionality. The mercury reservoir was at 21°.

IX.

Pressure	$A = K\,\delta_H/\delta_{Hg}$	$B = I_H/I_{Hg}$	B/A
1	1	0.75	0.75
2	2	1.7	.85
3	3	2.3	.76
4	4	3.2	.80
6	6	4.2	.7
8	8	3.5	.4

The relation between the intensity of the mercury line and the vapor pressure of mercury, as deduced from the curves in Fig. 2, is shown below:

X.

Temp.	$P \times 10^6$	Pressure=1 mm		Pressure=2 mm		Pressure=5 mm	
		I	P/I	I	P/I	I	P/I
−5°	116	3	39	1.3	90	...	...
+3°	220	5.5	40	3	73	1.6	140
+11°	530	11	48	6	88	3.5	150
+21°	1350	30	45	18	75	10	135

These results vary irregularly but within the limits of experimental error, and indicate proportionality between luminosity and vapor density, assuming that in each case the current at a given hydrogen pressure is the same. It seems hardly likely that such small quantities of mercury vapor can materially affect the current strength. Warburg[1] has shown that mercury vapor does not appreciably alter the cathode fall in a hydrogen tube, although present in sufficient quantities to give a bright spectrum.

The curves in Fig. 2 show that, while the luminosity of *Ha* at a pressure of 3 mm is practically unaffected by mercury vapor from the reservoir at temperatures below 7°, it is reduced by

[1] WARBURG, *Wied. Ann.*, **31**, 574, 1887.

more than half by mercury vapor from the reservoir at 21°. The same is true of $H\beta$, and to a slightly less extent of the green region of the compound spectrum. No measurements were made in other parts of the compound spectrum, but they were observed to diminish in luminosity in about the same proportion, so that the visible spectrum as a whole loses at least half its luminosity. The relative densities of mercury vapor at 3° and at 21°, and of hydrogen at 3 mm pressure are

$$\frac{0.00022}{3 \times 2} \times .200 = 0.0073 \text{ and } \frac{0.00135}{3 \times 2} \times 200 = 0.045.$$

The addition, therefore, to hydrogen at 3 mm pressure of less than 4 per cent. of its own mass of mercury vapor, or of one molecule of mercury to every 2500 molecules of hydrogen, will deprive the latter of more than one half its visible radiant energy.

The cause of this phenomenon is not easily seen. E. Wiedemann[1] suggested that in general metallic vapors may conduct electricity better than non-metallic vapors, as indicated by his experiments previously referred to. Similar phenomena have been observed by others. It is well known that the presence of small quantities of sodium or potassium in the electric arc will almost extinguish the carbon spectrum. Trowbridge[2] states that the presence of 30 per cent. of iron in the arc will completely obliterate the carbon spectrum. On the other hand, J. J. Thomson[3] and others have found that while some metallic vapors conduct about as well as dissociable non-metallic gases, hot mercury vapor is almost an absolute nonconductor. The facts shown in these experiments, that very small quantities of mercury vapor do not affect the hydrogen spectrum, that the luminosity of the mercury vapor is proportional to its density, and that the relative luminosities of hydrogen and mercury are proportional to their relative densities, do not seem to indicate that any disproportionate share of the total energy is imparted to the mercury vapor by the current. It seems probable that some other explanation

[1] WIEDEMANN, *Wied. Ann.*, **5**, 517, 1878.

[2] TROWBRIDGE, *Phil. Mag.*, **41**, 450, 1896.

[3] J. J. THOMSON, *Phil. Mag.*, **29**, 364, 441, 1890.

must be sought. Similar effects are observed in flame spectra, in which there is no question of division of current. When salts are placed in a flame, only the spectra of the metallic components (or of the compound if undissociated) can be seen, and in the solar spectrum hydrogen, helium, carbon, and silicon are the only non-metals which have contributed recognized lines.

Professor Warburg has suggested to me that the luminosity may be an indirect effect of the current, the direct effect being the generation of invisible rays of some kind (comparable to cathode rays), by the absorption of which the luminosity is produced. If, now, these rays are strongly absorbed by the mercury vapor, the spectral sensitiveness of this substance, as well as its diminishing effect on the luminosity of the hydrogen, may be explained.

THE EFFECT OF OXYGEN ON THE HYDROGEN SPECTRUM.

Some observations taken on hydrogen which had not been entirely freed from oxygen showed marked irregularities, and the luminosity of $H\alpha$ did not reach a maximum except at much lower pressures than in the case of pure hydrogen, or the maximum was less sharply defined. The same phenomenon was also observed when traces of air (and, therefore, oxygen) remained in the tube. Under these conditions mercury vapor appeared to have a less marked effect in reducing the luminosity of the hydrogen spectrum.

By gently heating the bulb *B* (Fig. 1), pure oxygen was evolved from potassium permanganate and introduced into the vacuum tube. The addition of some 3 per cent. of oxygen to pure hydrogen (as determined by change of pressure) reduced the luminosity of the discharge so much that no spectrum was visible. By diluting with more hydrogen a faint, apparently continuous, spectrum appeared; on further dilution $H\alpha$, $H\beta$, and the green mercury line (from traces of mercury left in the tube) were also seen. It was only after several dilutions in the drying tubes, when the proportion of oxygen remaining was very small, that the intensity of the hydrogen spectrum became measurable. The results are given below:

Number of dilutions	Pressure	$H\alpha$	Compound spectrum in green
III	0.8	10.6	2.5
	1.8	8.2	2
	2.6	3.6	0.8
	3.2	2	0.8
	5	1.5	0.3
IV	0.6	18	3.1
	1.2	16.3	3.1
	2.2	8.2	3.1
	3.1	5.3	2.5
	5	3.6	0.8
V	0.7	18	3.6
	0.9	18	3.6
	1	18	3.1
	1.2	20	4.5
	1.3	20	3.9
	2.3	20	4.5
	2.9	20	4.5
	3.2	20	4.5
	4	18	4.5
	4.5	13	3.6
	5.7	6	3.1
	7.5		
VI	0.7	36	..
	1	42	..
	1.1	42	..
	1.7	42	..
	2.1	39	..
	3.6	22	..
	6	13.3	..
VII	0.6	47	..
	0.8	45	..
	1.1	49	..
	1.2	47	..
	1.7	49	..
	1.8	53	..
	1.9	49	..
	2.4	45	..
	4	28	..
	6	26	..
VIII	0.6	42	..
	0.9	70	..
	1.1	73	..
	1.9	81	..
	2	81	..
	2.2	76	..
	2.9	70	..
	3.6	65	..
	4	39	..

Number of dilutions	Pressure	$H\alpha$	Compound spectrum in green
Almost pure hydrogen	0.7	33	..
	1.2	57	..
	1.4	57	..
	2.6	76	..
	2.8	70	..
	3.6	70	..
	4.2	53	..
	5	36	..

The results are shown in Fig. 3. The lower broken curves represent the luminosity of the compound spectrum in the green in series II and V, above given.

These curves show:

1. A displacement of the maximum luminosity toward lower pressures, increasing with the proportion of oxygen.

2. A diminution of the luminosity of $H\alpha$ at pressures above 1 mm, an increase at pressures below 1 mm. Paalzow and Vogel[1] observed a strengthening of the oxygen spectrum by the addition of traces of hydrogen.

A portion of the mixed gases, through which the discharge had passed, was left overnight in the tube. The next morning $H\alpha$ again showed a sharply defined maximum at 3 mm. Apparently the gases had been combined by the current and the water vapor had been absorbed by the drying tubes.

When mercury vapor from the reservoir at 20° was admitted, it did not reduce the luminosity of hydrogen to such an extent as when no oxygen was present. In fact, $H\alpha$ showed a greater luminosity at pressures above 2 mm, but smaller luminosity at smaller pressures. This is shown in Fig. 4. The explanation is probably the following: At pressures above 2 mm the mercury removes a part of the oxygen by combination, thus increasing the purity and intensity of the hydrogen spectrum. Below 2 mm the absolute quantity of oxygen present is so small that it is completely removed by the mercury, which then reacts on the hydrogen in its characteristic way.

[1] PAALZOW and VOGEL, *Wied. Ann.*, 13, 337, 1881.

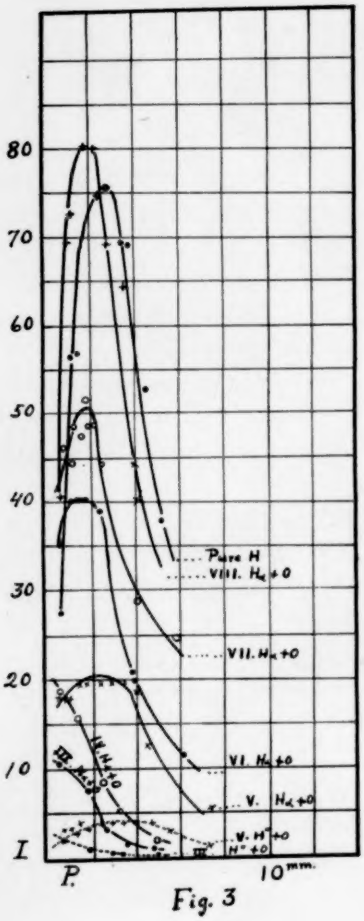


Fig. 3

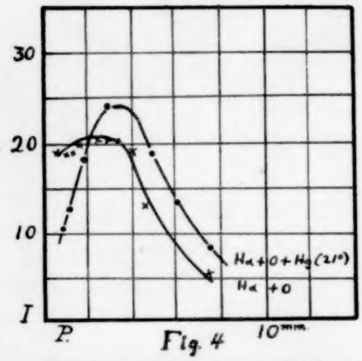


Fig. 4

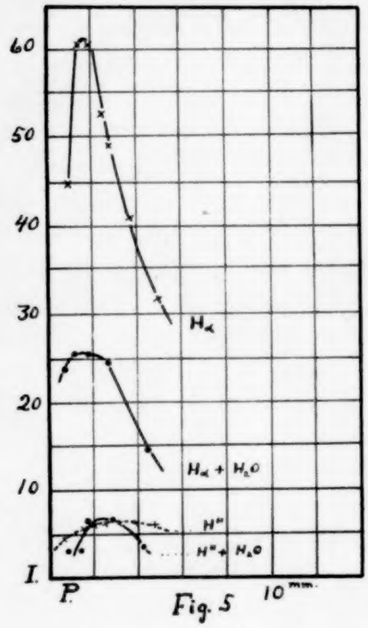


Fig. 5

With still smaller quantities of oxygen present mercury vapor was several times introduced. The initial effect was always smaller than with pure hydrogen, but after a little time the intensity of *Ha* diminished to about the value obtained with no oxygen present. This is consistent with the above explanation.

The presence of oxygen changed the color of the discharge in the capillary from pale pink to a dull feeble red.

THE EFFECT OF WATER VAPOR ON THE HYDROGEN SPECTRUM.

The mercury reservoir *E* was replaced by a bulb containing an almost concentrated solution of sulphuric acid in water, which was cooled to 3°. The vacuum tube was several times pumped out, heated, and filled with pure dry hydrogen, and measurements made of the luminosity of *Ha*. The position of the maximum indicates that small traces of oxygen still remained.

Water vapor was then admitted from the bulb. The vapor pressure must have been exceedingly small, but a very noticeable effect was almost instantly observed.

The results are given below and shown in the curves of Fig. 5. The lower broken curves represent the luminosity of the compound spectrum.

XII.

	Pressure	*Ha*	Compound (Green)
Dry hydrogen	0.9	45	5
	1.4	61	6
	1.7	61	7
	2.3	53	7
	2.9	49	7
	3.8	42	7
	4.9	33	7
Water vapor present	0.8	24	3.6
	1.1	26	3.6
	1.6	26	7
	2.7	20	7
	4.2	15	4.5

The effect of water vapor is quite similar to that of oxygen, as might be expected. These observations were repeated many times with similar results. Usually the effect on the compound spectrum was greater than that shown above.

After shutting off the water vapor and opening communication with the drying tubes the hydrogen gradually increased in luminosity.

These effects may be related to those observed by Warburg,[1] who found that very small quantities of water vapor noticeably influenced the cathode fall in hydrogen. The great reduction in luminosity, caused by water vapor, however, need not necessarily imply that the current strength is greatly reduced by its presence. The total radiation, invisible as well as visible, as well as the nature of radiation in vacuum tubes, must be known before we can determine the exact relation between luminosity and current strength.

THE COMPOUND HYDROGEN SPECTRUM.

In none of these experiments was the compound spectrum of hydrogen absent. The presence of traces of mercury vapor, oxygen, or water vapor materially reduced the luminosity of both the elementary and the compound spectrum, and with a very narrow slit the latter often seemed very feeble. It is probable that, working with a very narrow slit and ordinary, not "end-on," tubes or with very great dispersion, the compound spectrum might have been entirely invisible in the presence of mercury vapor, water vapor or oxygen. It seems doubtful whether an absolutely isolated elementary spectrum has ever been observed in pure hydrogen at low pressures. Lagarde[2] obtained what appeared to be a pure line spectrum, with no trace of the compound, only when water vapor was present, and then the intensity of the line spectrum itself was greatly reduced by the presence of the water vapor. He did not use "end-on"

[1] WARBURG, *Wied. Ann.*, **31**, 575, 1887.

[2] LAGARDE, *Ann. Chim. et Phys.*, **4**, 265, 1885.

tubes. Salet[1] and Cornu[2] obtained a "pure" elementary spectrum only after the tube had been repeatedly washed out with oxygen. It seems possible that traces of oxygen remained, and made the compound spectrum very weak. Ames,[3] Schumann,[4] and Hutton[5] never succeeded in eliminating the compound spectrum. Schumann found it strongest in the tubes which had been most carefully cleaned, and weakest in those which had not been cleaned at all, and which, therefore, probably contained compounds capable of giving off oxygen or water vapor. Hutton found that it was much weaker after washing the tube with oxygen. Trowbridge,[6] using a very large condenser, produced an elementary line spectrum of hydrogen in which no compound spectrum was seen. The three last-named observers, as well as myself, have observed that the discharge in hydrogen giving the purest elementary spectrum is red; when the compound spectrum is strong, it is very pale pink or nearly white at low pressures, bluish-white at higher pressure.

In these series of experiments it has been observed that in pure hydrogen the intensities of the elementary and the compound spectrum rise and fall together, with changes in current and density, although not in the same proportion. Changes in both spectra, due to mercury, oxygen, and water vapor, are qualitatively, if not quantitatively, the same. In spite of the many doubts which have been raised, it seems impossible to escape the conclusion that this compound spectrum is really due to hydrogen, not to impurities. Furthermore, since the two spectra seem almost invariably coexistent throughout a very wide range of physical conditions, it seems possible that they may not be essentially different, but parts of one and the same spectrum. The differences in their appearances under different physical

[1] SALET, *Ann. Chim. et Phys.*, **28**, 22, 1871.

[2] CORNU, *Jour. de Phys.* (2), **5**, 100, 1886.

[3] AMES, *Phil. Mag.*, **30**, 50, 1890.

[4] SCHUMANN, *Jahrbuch. f. Phot.*, **8**, 1894; *Wied. Beiblätter*, **18**, 752, 1894.

[5] HUTTON, *Phil. Mag.*, **46**, 338, 1898.

[6] TROWBRIDGE, *Phil. Mag.*, **43**, 137, 1897.

conditions are hardly more striking than those observed between lines generally accepted as belonging to the same spectrum — the green and yellow lines of mercury, for example, as the vapor density changes.

II. OXYGEN.

In some previous experiments, in which a tube with internal electrodes was used with no valve between the pump and the tube, it was observed that in an atmosphere of pure oxygen the spectrum due to mercury vapor from the pump was entirely absent. Eisig[1] also found that the mercury lines did not appear in oxygen tubes.

The addition of a very small trace of hydrogen caused the green line instantly to appear. Further experiments with internal electrodes were made to confirm this observation.

The tube was filled with pure oxygen generated from potassium permanganate. Even at low pressures the luminosity of the discharge was very small, and only an exceedingly faint, apparently continuous, spectrum could be seen. After the current had passed for several minutes, the discharge changed from dull pink to white, and the red hydrogen line and carbon monoxide bands appeared. After washing out the tube several times with oxygen the latter were permanently weakened.

Fresh oxygen being in the tube, communication was opened with the mercury reservoir at 20°. Although ample time was allowed for diffusion, the green line did not appear until $H\alpha$ appeared.

A trace of fresh hydrogen was added. The only effect was to slightly increase the intensity of the hydrogen and mercury lines. At no time did any oxygen lines appear, nor the green mercury line unless hydrogen was also present.

With the mercury reservoir open, the green line flashed out brilliantly at the instant the discharge began to pass, then faded to a small intensity. If the current was immediately turned on again, the flash did not reappear, but it always did after the few

[1] EISIG, *Wied. Ann.*, **51**, 750, 1894.

seconds necessary for fresh mercury vapor to diffuse into the capillary tube. This flash was evidently due either to the passage of the discharge through the uncombined mercury vapor or to the act of chemical combination itself. That combination did occur was evident from the reduction of pressure in the tube. In one case it fell from 1.9 to 0.8 mm within a few minutes, while the current was passing.

The mercury reservoir was cooled down to $-13°$. This produced no alteration whatever in the intensity of the green line, as in the experiments with hydrogen, in which the luminosity of the mercury responded rapidly and unfailingly to the changes of temperature of the reservoir. Heating the tube also caused a great increase in the intensity of this line (in one case from 13 to 87), and also brought out the yellow lines. A steady stream of fresh hydrogen did not weaken the intensity of the mercury spectrum. These facts indicate that the mercury was not present in the form of free vapor, but as mercuric oxide, and offer an explanation of the great difficulty previously experienced in completely eliminating the green line from the hydrogen spectrum.

As the oxygen disappeared, the intensity of both hydrogen spectra increased, that of the compound faster than the elementary. In one case the intensity of $H\alpha$ increased from 20 to 49, that of the compound spectrum in the green from 1 to 20. These changes are doubtless in part due to the change in pressure, partly to the varying purity of the hydrogen.

CONCLUSIONS.

1. Very small traces of an impurity in a gas may cause considerable changes in its spectrum, whether this impurity be chemically active or not.

2. The addition to pure hydrogen of very small traces of mercury vapor will cause the green mercury line to appear in the spectrum. Under the conditions prevailing during these experiments, the green line did not disappear until the supply reservoir was cooled to below $-20°$. At this temperature the saturated

vapor pressure of mercury is only 0.000016. At ordinary temperatures the green line remained plainly visible at hydrogen pressures above 10cm, when only an exceedingly faint, apparently continuous, hydrogen spectrum was visible. The luminosity of mercury vapor, mixed with hydrogen at a given pressure, was found to be nearly proportional to the density of the mercury vapor. The yellow and blue lines appeared only at temperatures above 10°.

3. The addition of small quantities of mercury vapor to pure hydrogen materially reduced the luminosity of both the elementary and the compound spectrum of the latter. The relative luminosities of the hydrogen and the mercury vapor seemed to be proportional to their relative densities below 6 mm hydrogen pressure. At higher pressures of hydrogen the mercury possesses relatively greater luminosity. The addition to hydrogen, free or nearly free from mercury vapor, of 4 per cent. of its own mass (or one molecule of mercury to every 2500 molecules of hydrogen) reduced the luminosity of the entire hydrogen spectrum by more than one half.

4. In tubes with external electrodes pure hydrogen showed a maximum luminosity at a pressure of about 3 mm, the conditions of current supply remaining constant. Tubes with internal electrodes under the same conditions gave no maximum down to pressures of about 0.6 mm. The position of this maximum is probably a function of the current strength and the size of the tube.

5. The addition of small quantities of oxygen to hydrogen caused considerable changes in the luminosity of the latter. The luminosity was increased at pressures under 1 mm, and diminished at higher pressures. The maximum luminosity of the hydrogen was shifted to lower pressures with increasing quantities of oxygen present.

6. Water vapor produces effects quite similar to those of oxygen. Water vapor is probably formed when the discharge passes through the mixture of hydrogen and oxygen.

7. The so-called "compound" spectrum of hydrogen is

really due to hydrogen, not to impurities, as has been often claimed.

8. A very small quantity of hydrogen added to oxygen will excite luminosity in mercury vapor present. The cause of this is not clear.

My thanks are due to Professor Warburg for his continuous advice and help during this investigation.

PHYSICAL INSTITUTE OF THE UNIVERSITY OF BERLIN,
July 1899.

ON PROFESSOR KEELER'S PHOTOMETRIC RESEARCHES, BY PHOTOGRAPHIC METHODS, ON THE NEBULA IN ORION.

By J. Scheiner.

In the March number of the Astrophysical Journal, Professor Keeler has given an account of some investigations, in which a photographic method is used to show that the quality of the light emitted by the Orion Nebula is different for different parts of the nebula.

The method is briefly as follows: A negative of the nebula was made on an ordinary plate, with short exposure, by means of a reflecting telescope; and another negative was made, with a longer exposure, on an orthochromatic plate, which was protected from the action of the more refrangible rays by a yellowish-green plate of glass. The exposure times were so chosen that the bright part of the Huyghenian region appeared equally strong on both plates. The result was, that on the color-sensitive plate the fainter details in the outlying parts of the nebula were much less conspicuous than on the ordinary plate. From this fact the following conclusion was drawn: "We infer, therefore, that in the remote parts of the nebula the two lowest nebular lines are weak, or the hydrogen lines strong, as compared with the Huyghenian region. Thus the results of spectroscopic researches are confirmed, and are extended to parts of the nebula which are too faint for visual observation."

This conclusion involves the theorem, which is also directly stated in another place, that equally dense parts of the negative correspond to equally bright parts of the object. This theorem is, however, incorrect, and can only be justified under two limitations: equal times of exposure and similar plates. These two limitations are necessary, because, in the first place, the product of time and intensity is not a constant, and because in the second

place, the complicated law which is to be substituted for it involves constants which have very different numerical values for different kinds of plates. In the research under consideration both these limits are very greatly exceeded — first, in the variation of the time of exposure from six minutes to two hours and twenty minutes, and second, in that an ordinary plate was brought into comparison with one which had been sensitized with erythrosin. The fact that, even with equal times of exposure, the different degrees of darkening by different grades of brightness may vary widely for different kinds of plates is so generally known, that professional photographers give special orders to factories for "hard" or "soft" plates, each to be used for its appropriate purpose. A further consideration of this point might therefore be deemed superfluous; but I wish very briefly to sketch an example of such investigations as should have preceded the conclusion which I have cited.

An ordinary Schleussner plate *a* was exposed in a sensitometer for thirty seconds, and an orthochromatic plate *b*, protected by a yellow color-screen, for five minutes. The darkest square 1 of plate *b* corresponded with the squares 3–4 of *a*. The faintest perceptible impressions were, for *b* the squares 15–16; for *a*, 14–15. The interval on *b* was therefore 15.5 squares and on *a* 11 squares; the corresponding intensity intervals are 33 and 11.3. If these plates had been used on the Orion Nebula, the result would, on the assumption of uniform quality of light, have been the reverse of that found by Professor Keeler. On the orthochromatic plate the outlying parts of the nebula could have been traced farther than on the ordinary plate. But we should have to guard ourselves against drawing the conclusion that the hydrogen lines are relatively weaker in the outlying parts than they are in the Huyghenian region; we should rather, on the basis of the experiments with the sensitometer, just mentioned, explain the observed appearance as being in harmony with the fact that in this case the orthochromatic plate was the "softer." With equal intensity of the brighter regions, it had rendered visible portions which were three times fainter than

those which appeared on the ordinary plate; and it is known that even greater differences may occur than those given in this example.

A particular interest, on the other hand, attaches to Professor Keeler's statement that on the orthochromatic plate the *Proboscis Major* is materially stronger than the streamer which is parallel to it, and which on an ordinary plate nearly equals it in intensity. If these two objects were in fact exactly equal in brightness this experiment would prove the correctness of the views held by Professor Keeler; but if there exists even a small difference of brightness, the conclusion is again inadmissible, since, according to the example of differences of plates, which I have given, small contrasts are vastly exaggerated photographically.

With respect to the method used by Professor Keeler, of weakening the brighter parts of the nebula, I have merely to say that the application of such methods, in the comparison of brightnesses which are already near the limit of visibility, seems to me a doubtful proceeding.

ROYAL OBSERVATORY, POTSDAM.
June 1899.

NOTE ON THE FOREGOING ARTICLE BY PROFESSOR SCHEINER.

By James E. Keeler.

The peculiarities of photographic action and of photographic plates referred to by Professor Scheiner are very well known to me, through both reading and daily experience, and I must observe that I have not really made the statement with which I am credited. My words are: "About all that it is safe to assume is, that (setting aside certain limiting conditions not likely to be met with in nebular photography) equally dense parts of the negative correspond to equally bright parts of the object." Here the reference is to one and the same negative, and, the exposure-times, the plate, and (by hypothesis) the quality of the light, being the same, the truth of the statement is self-evident.[1]

This, however, is not an important matter. Professor Scheiner's main objection has a valid theoretical basis; and if the plates I used had been more unlike in their properties, if the differences I have described were less strongly marked, and if no other evidence were available than that criticised by Professor Scheiner, I might have felt some doubt as to the justness of my conclusions. The difference between the plates is, however, not sufficient to explain the difference between the negatives. There is also the other evidence afforded by the photograph to be considered, to say nothing of the spectroscopic observations. If the question were merely one of the plates, all parts of the image which are equally dense on the ordinary plate should also, if the quality of the light is everywhere the same, be equally dense on the isochromatic plate, which is not the case. And, as I have pointed out, all the stars, even the

[1] Possibly the source of the misunderstanding lies in the fact that a noun in its widest or most general sense is used in German with the definite article, but in English with the indefinite article.

faintest, in the outlying regions, are at least as strong on the isochromatic as on the ordinary plate, though the nebulosity which surrounds them is missing.

In the special case of the Messerian branch which I have brought forward, Professor Scheiner objects that the brightness is still not exactly equal to that of the parallel streamer with which I have compared it, but somewhat greater. This is true; but again I would say that the effect is disproportionate to the cause which Professor Scheiner assigns to it. The brightness is in fact so nearly the same that to obtain a comparison free from theoretical reproach it is only necessary to choose a part of the Messerian branch lying toward its eastern side, for the brightness falls off gradually in that direction. The difference between the negatives remains, however, and the conclusion is unaffected.

With regard to the experiments in which the spectrum of the Huyghenian region was dimmed, for comparison with the spectrum of the region surrounding the star Bond 734, I would say that the observation is really not a difficult or delicate one. There is plenty of light for the purpose. I am confident that Professor Scheiner's own doubts would be resolved at once if he could repeat this observation with our thirty-six-inch refractor.

LICK OBSERVATORY,
University of California,
August 1899.

THE POSITION OF THE STARS OF TYPE IV AND OF THE VARIABLE STARS OF TYPE III IN REFERENCE TO THE MILKY WAY.

By T. E. Espin.

Dr. Dunér has shown (*Sur les étoiles à spectres de la troisiéme classe*, p. 26) that the stars of Type IV have a distinct tendency to collect in the Milky Way. As in the last few years the discoveries of the stars of Type IV have made it almost certain that we now know all of them down to 8.5 mag. in both hemispheres (excluding those that are unsteady in light), it seemed of interest to examine Dr. Dunér's statement afresh. For this purpose two charts were drawn representing the heavens, and the places of 10°, 20°, 30°, etc., of Galactic longitude and latitude were calculated and laid down. The stars of Type IV were inserted, and the number of stars in each zone of 10° of Galactic latitude counted. As regards the Galactic longitude it was found that the IV Type stars were fairly evenly distributed, no special grouping being noticeable with the exception of that at G. long. 43° in the constellation of Cygnus.

The results in latitude are shown in the following table:

TABLE I.

Gal. lat.	N. lat.	S. lat.	Total
0°—10°	60	63	123
10 —20	24	19	43
20 —30	15	12	27
30 —40	4	9	13
40 —50	7	1	8
50 —60	1	4	5
60 —70	1	1	2
70 —80	2	0	2
80 —90	0	1	1
Total -	114	110	224

This result entirely confirms that of Dr. Dunér. Of the stars of Type IV, 74 per cent. lie within 20° of Galactic latitude.

The variable stars of Type III were next treated in a similar manner. Stars where the variation is small and where the hydrogen lines are not bright were rejected. Some of the later discoveries have not been examined with the spectroscope, and in a few cases may turn out to be of Type IV, but there are too few to affect the general results. The following table gives the results:

TABLE II.

Gal. lat.	N. lat.	S. lat.	Total
0°—10°	25	23	48
10 —20	29	25	54
20 —30	32	33	65
30 —40	17	29	46
40 —50	10	14	24
50 —60	17	15	32
60 —70	10	3	13
70 —80	1	4	5
80 —90	1	5	6
Total -	142	151	293

This table seems to show that the variable stars have a tendency to collect on the borders of the Milky Way. There is also a distinct tendency to grouping, such groups occurring at:

Gal. long.	Gal. lat.	Constellation
30.8°	17° S	Delphinus
53.3	19 N	Cygnus
173.9	12 N	Canis Minor
321.0	23 N	Libra
325.9	18 S	Sagittarius
346.9	14 S	Sagittarius

The results obtained in Table II seemed worthy of further investigation. For this purpose the latitudes of all the variable stars were approximately obtained from the two charts between 10° and 30° of Galactic latitude. The mean of the latitudes was

then taken for N. and S. in each map. The following are the results:

TABLE III.

	No. of stars	Mean Galact. lat.	No. of stars+25°	No. of stars−15°
Map I, S	23	19.0°	3	5
N	22	20.8	5	3
Map II, S	36	20.7	7	4
N	40	19.9	5	6
	Total 121	Mean 20.7°	Total 20	Total 18

The fourth and fifth columns give the number of stars 25° to 30° and 10°–15°. They show that the decrease on each side of 20° is nearly equal. Further, added together they give 38 for the ten degrees, while the zone 15° to 25° has 83, thus showing the aggregation to be real. Rejecting then the stars more than 5° from the mean found in Table III, we get

		No. of stars		Mean Gal. long.
Map I, S		15		19.7°
N		14		20.5
Map II, S		25		20.2
N		29		20.3
	Total	83	Mean	20.3°

An inspection of Table II shows that there is a second apparent maximum at from 50°–60°. This treated in a similar manner gave as a result mean Galactic latitude 57.3°, but with great uncertainty.

Summarizing the results of this paper the following propositions seem warranted:

(1) The stars of Type IV, and the variable stars of Type III are distinctly related to the Galaxy.

(2) Of the IV Type stars 55 per cent. are found within Gal. lat. 10°.

(3) The IV Type stars are fairly evenly distributed in Gal. long.

(4) The largest number of the variable stars of Type III are found on the borders of the Galaxy.

(5) This zone is from 15° to 25° of Galactic latitude.

(6) These variable stars show a tendency to form into groups.

I have in addition investigated the variation and period of these stars and can find no connection with their position in reference to the Galaxy. Lastly to trace any connection between the variable stars and the stars of Type III, I plotted down all the known variables of III !! and III !!!. These show a distinct tendency to grouping, but not with any reference to the Galactic latitude of 20° as in the case of the variable stars. The third type stars increase in number as the Milky Way is approached, and in two of the cases, where there are groups of variables in Cygnus and Delphinus, the third type stars group as well; on the other hand, there is a strong group at Gal. long. 60°, lat. S. 28°.

Tow Law, Darlington, England.
July 6, 1899.

OBSERVATIONS OF COMET SPECTRA.

By W. H. WRIGHT.

COMET 1898 I (*Perrine*).

THE spectrum of this comet was observed visually on May 9, 1898. It was of the usual type: the three characteristic bands superposed on continuous spectrum, which was relatively strong. Photographic observations were not made.

COMET 1898 VII (*Coddington*).

Observations on June 11 by Professor Campbell and the writer showed the spectrum to be of the usual type, except that the banded spectrum was very faint as compared with the continuous. The yellow and blue bands were seen only with difficulty. To the writer the banded spectrum seemed to be stronger in the outlying parts than in the nucleus. The spectrum was again observed on June 16 with practically the same results, except that the bands in the nucleus seemed to be relatively stronger than on the previous occasion. The spectrum was too faint to be photographed.

COMET 1898 X (*Brooks*).

Observations were made on November 3, 1898, by Professor Campbell and the writer. The three chief bands were easily visible, the one in the green being apparently much brighter than usual. It was roughly estimated as being from four to six times as bright as the others. The continuous spectrum was very weak, being visible only in the nucleus with a wide slit Nothing was visible above or below the three bands.

COMET 1899 *a* (*Swift*).

The visible spectrum of this comet resembled that of 1898 X, inasmuch as it consisted almost entirely of bright lines. The

three carbon bands were bright, but the dispersion used was too low to show further details.

The spectrum was photographed with a spectrograph attached to the twelve-inch equatorial on May 4, 8, and 11. The photograph of May 8 was the best, showing the blue band resolved, and the cyanogen lines at λλ 3871 and 3883, with considerable detail between.

Further photographs were obtained on June 5 and 6 with a spectrograph attached to the thirty-six-inch telescope. By the use of a correcting lens, placed one meter in front of the slit, a color curve satisfactory for this class of work is obtained over the entire region covered by the spectrograms. The following are the results of measurements:

June 5	June 6		
3870	3869	Very bright, slightly hazy to violet	3871.5 Cyanogen
3881	3879	V. V. bright, very sharp	3883.5 Cyanogen
399	3987	Faint and somewhat hazy	
	4014	Bright, resolvable with difficulty	
4019	4019		
4041	4042	Bright and rather broad	
4053	4052	V. bright, sharp	
4074	4074	Fairly bright; looks like head of band extending toward violet	
4101	4100	Faint	
	413	V. faint	4128.1 Cyanogen
421	421±	V. faint	4216.1 Cyanogen
	4313		
	435	Suspect faint band with faint line at 4369	436 (?) 5th carbon group
	440		438
	472	Center of gravity of blue band, which is out of focus	4th carbon group
	4883	Suspected bright line	

The slight correction (—¼ A. U.) for motion of the comet in the line of sight has been taken account of, but the results are uncorrected for the effect of slit-width as discussed by Professor H. Kayser (*A. and A. P.*, **13**, 367). The general shift toward the violet indicated by the spectrogram of June 6, is not, however, entirely to be accounted for by the Kayser effect, as will be seen by the following consideration: The hydrogen tube used on

this date for comparison contains an impurity giving the bands at $\lambda\lambda$ 3871 and 3883. With reference to these the corresponding comet bands are perceptibly shifted toward the violet. The spectrograph used in these determinations is one constructed for the purpose, and which has not otherwise been tested. Although it is in many respects most efficient, I am inclined to consider that the shift referred to is instrumental, the result probably of manipulation of the slit while photographing the comparison spectrum.

Most of the lines here observed have counterparts in the spectra of carbon and cyanogen, and the majority of these are doubtless to be accounted for by the presence of the two substances. In addition to those indicated above there is a line of wave-length 4099.2, which approximates closely to that of the comet line 4101. Professor Kayser, however, thinks the two are not identical, the cyanogen line being in his opinion much too faint. The identity of the comet line being open to doubt, it is of interest to note that it is very close to $H\delta$ (λ 4101.9). The proximity must not, however, be held to prove identity.

In appearance, the head of the comet was very diffuse, with a nucleus some 4″ in diameter. In the spectrum of the nucleus λ 4052 is fully as bright as λ 3870, but the latter line extends out into the fainter parts of the comet's head more than four times as far as the former. In fact the lines $\lambda\lambda$ 3870 and 3880 experience only a gradual increase in brightness in the region of the nucleus, and extend the entire length of the slit. In the cases of all the other lines the change is quite abrupt. This must be taken to indicate a marked difference between the spectrum of the nucleus and the spectra of the outer parts of the head.

The spectrograms have been compared with some of comet 1893 *b* (Rordame) and 1894 *b* (Gale), secured by Professor Campbell with a spectrograph attached to the thirty-six-inch telescope. The correspondence is not exact, as Professor Campbell had not the advantage of the photographic corrector referred to above. This accounts sufficiently for such differences as exist in the estimates of relative intensity of the lines. Taking into

consideration the difference in color curves there is no evidence of any variation in the type of spectrum.

The constants of the spectrograph used in these determinations are:

Length of collimator	81. cm
Length of camera	30.5 cm
Slit width	0.1 mm
Effective aperture of lenses	4.27cm

Dispersion between D and $H\gamma$, 57′ 10″.

THE SPECTROSCOPIC BINARY CAPELLA.

By W. W. CAMPBELL.

AN examination of six spectrum plates of α Aurigae, obtained with the Mills spectrograph in 1896–7, leaves no doubt that this star is a spectroscopic binary. The spectrum is composite. The component whose spectrum is of the solar type furnished the following velocities with reference to the solar system:

1896 Aug. 31	+ 34 km
Sept. 16	+ 54
Oct. 3	+ 49
Oct. 5	+ 44
Nov. 12	+ 4
1897 Feb. 24	+ 3

On the first photograph the spectrum is of essentially normal solar type; on the others it is unmistakably different. There appears to be a second component whose spectrum contains the $H\gamma$ line and the rather prominent iron lines. On the plates of September 16, October 3, and October 5, these lines are shifted toward the violet with reference to the solar type spectrum; and in the spectra of November 12 and February 24 they are shifted toward the red.

LICK OBSERVATORY,
August 10, 1899.

THE VARIABLE VELOCITIES IN THE LINE OF SIGHT OF ϵ LIBRAE, h DRACONIS, λ ANDROMEDAE, ϵ URSAE MINORIS AND ω DRACONIS.

By W. W. CAMPBELL.

ϵ LIBRAE ($\alpha = 15^h\ 18.8^m$, $\delta = -9°\ 57'$).

THE variable velocity of this star, detected several months ago, is indicated by the following results:

1899	April 13[1]	− 8 km
	May 10	+12.2
	15	+ 7.5
	June 12	− 7.5
	14	− 7.0
	26	−11.2
	July 13	−10.8

The period is undetermined, but it seems to exceed three months.

h DRACONIS ($\alpha = 16^h\ 55.4^m$, $\delta = +65°\ 17'$).

The velocities obtained for this star are:

1899	June 26	−26 km
	July 11	−36
	16	−32
	24	−16

The period remains undetermined.

λ ANDROMEDAE ($\alpha = 23^h\ 32.6^m$, $\delta = +45°\ 56'$).

The reality of the variations indicated by the first three plates, noticed in June, is amply confirmed by five later plates. The velocities obtained up to date are as follows:

[1] An underexposed plate, not suitable for accurate measurement.

1897	Nov.	16	+16km
1898	Oct.	18	− 2
		26	+13
1899	July	5	+15
		11	+ 3
		12	+ 2
		16	+ 1
		24	+14

The observations are apparently satisfied by a period of about 19.2 days.

ϵ URSAE MINORIS ($\alpha = 16^h\ 56^m$, $\delta = +82°\ 12'$).

The velocities observed for this star are as below:

1897	May	5	+ 3km
		27	−35
	July	21	−10
	Aug.	4	+ 9
1899	July	31	−40

The period remains undetermined.

ω DRACONIS ($\alpha = 17^h\ 37.5^m$, $\delta = +68°\ 48'$).

The velocity of this star in the line of sight varies rapidly. Four spectrograms give the following results:

1899	July	25	+18 km
	Aug.	8	−45
		9	−12
		29	−53

Compared with the whole number of stars for which plates have been secured with the Mills spectrograph, the nine or ten spectroscopic binaries recently discovered here seem to indicate that these systems are at least as plentiful as visual binaries. The observations for determining the orbits of these bodies are well up to date, and for several of them are practically completed.

Acknowledgments are due to Mr. Wright for his skillful assistance in the observations.

THE VARIABLE VELOCITY OF *a* URSAE MINORIS IN THE LINE OF SIGHT.[1]

By W. W. CAMPBELL.

POLARIS furnishes an interesting case of variable velocity in the line of sight. Six spectrograms were obtained in 1896, as follows:[2]

Gr. M. T. 1896, Sept.	8ᵈ	22.8ʰ	—20.1 km
"	15	22.8	—19.1
"	23	21.4	—18.9
Oct.	5	21.0	—19.0
Nov.	11	19.3	—20.1
Dec.	8	16.7	—20.3
		Mean	—19.6

The agreement of these results was satisfactory, and gave no evidence of variable velocity.

Gr. M. T. 1899	Velocity	Measured by
August 9^d 0.8^h	—13.1	Campbell
9 20.1	—11.4	Campbell
14 22.8	— 9.0	Campbell
16 0.1	—14.1	Campbell
23 0.3	—10.9	Campbell
24 0.8	—15.2	Campbell
26 0.9	— 9.4	Campbell
*	— 8.6	Wright
27 0.3	—10.6	Campbell
27 16.2	—14.0	Campbell
28 0.8	—14.7	Campbell
*	—14.3	Wright
28 16.3	—13.7	Wright
29 0.4	—12.1	Wright
29 18.8	— 9.6	Wright
30 0.0	— 8.9	Wright
30 16.2	— 9.3	Wright

*Measures of the same plate by Mr. Wright.

[1] Read at the Third Conference of Astronomers and Astrophysicists, Sept. 8, 1899.

[2] Published in this JOURNAL, October 1898, p. 149.

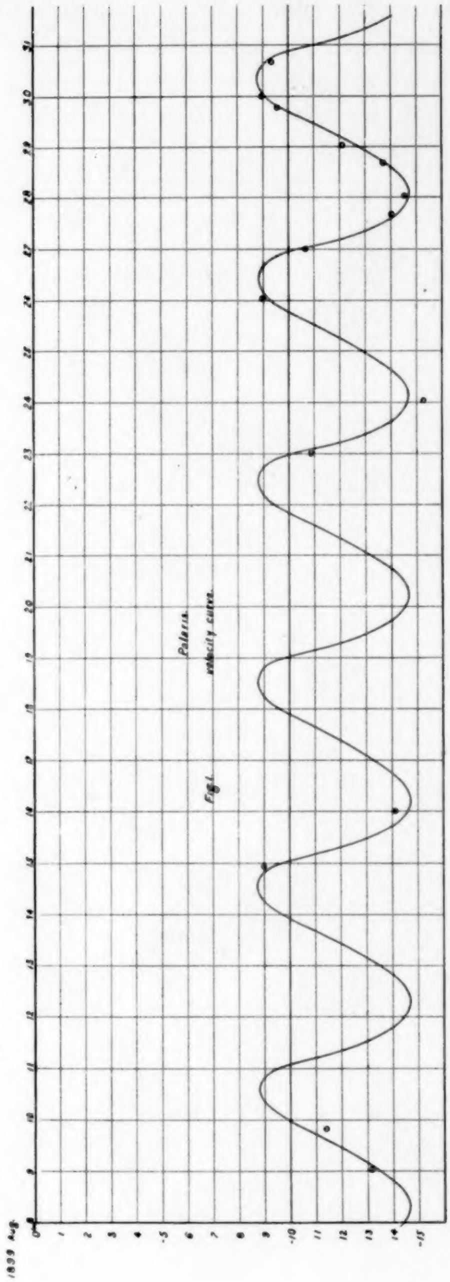


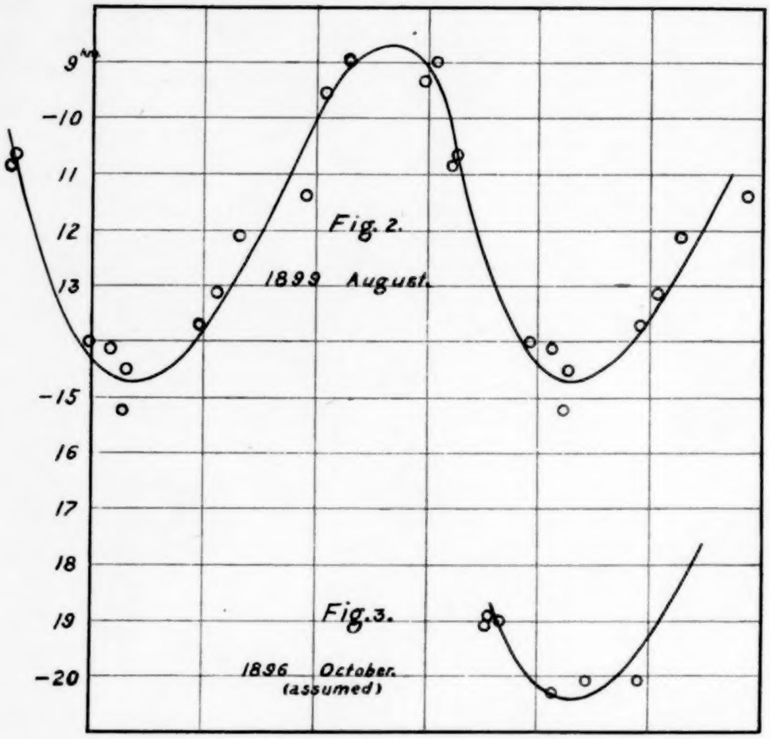
Fig. 1.—Velocity Curve of Polaris.

In order to test the current results of our work with the Mills spectrograph, another photograph of the spectrum of Polaris was obtained on Aug. 8, 1899. This yielded a velocity of —13.1 km, and led to the suspicion that we were dealing with a variable. Two additional plates were secured on August 9 and 14, which yielded velocities of —11.4 and —9.0 km, respectively. Inasmuch as a range of 4 km is not permissible in the case of such an excellent spectrum, the star was suspected to be a short period variable, and further observations were obtained, as on page 180.

On plotting these observations, Fig. 1, it became evident that Polaris is a spectroscopic binary, having a period a little less than four days. The 1899 observations have been collected and plotted, in Fig. 2, on the assumption that the period is

$3^d\ 23^h$. The velocity, at present, seems to be included between —8.6 and —14.6 km, having an extreme range of only 6 km. The velocity of the binary system seems to be about 12 km.

The determinations of velocity made in 1896 lie entirely outside of the present range of values, and leave no doubt that the



velocity of the binary system is changing under the influence of an additional disturbing force. I think it is certain, therefore, that Polaris is at least a triple system.

The 1896 observations were made at intervals differing but little from multiples of the period of the binary system, and therefore fell near the same point in the velocity curve. Assuming a period of $3^d\ 23^h \pm$, there is no difficulty in selecting the epoch of minimum so that these six observations will fall on the

curve satisfying the 1899 observations. The residuals will be negligible if we assume the observations to fall near the lower part of the curve, as in Fig. 3; and I have no doubt that future determinations of the orbit will definitely place them there. It will be seen, on comparing Figs. 2 and 3, that the velocities of the binary system in 1896 and in 1899 differ about 6 km.

Lick Observatory,
Sept. 1, 1899.

THE VARIABLE VELOCITY OF POLARIS.

By Edwin B. Frost.

Polaris has not been on the regular working list of stars whose velocities are to be determined at the Yerkes Observatory; but in view of the interest in Professor Campbell's important discovery, it seems desirable to give at once the results of the measurements I have just made on three plates recently secured, which confirm the short period variation in the velocity.

The velocities are:

1899, August	10,	20.8^h G. M. T.	-12.0 km
Sept.	20,	19.2	-17.7
	27,	16.0	-10.6

The first plate was taken under unfavorable circumstances, with a short camera of 271 mm focus, and would be called a poor plate. The velocity is based upon the displacements of six star lines, titanium being used for comparison. The result, however, may be expected to be reliable within three kilometers.

The second plate is an excellent one, taken with a camera of 456 mm focus. The probable error of the above mean of the determinations from 12 lines is ± 0.59 km. The third plate is equally good. The probable error of the mean of the 16 lines measured is ± 0.48 km. The three plates were photographed by Mr. Ellerman.

On locating the second observation on Professor Campbell's curve by reckoning forward with a period of $3^d\ 23^h$ from his minimum of -15.4 km on August 24, it appears that the observation (Sept. 20) falls within a little over an hour of a minimum. It will be seen that the third plate also falls close to its expected position on the curve.

A fourth plate, secured, as was the third, while this was passing through the press, and not yet measured, appears on inspection to give a result accordant with the curve.

The range of variation, 7 km, is within a kilometer of that found by Professor Campbell.

Of course my observations cannot give testimony on the question of a long period motion in the system of Polaris.

YERKES OBSERVATORY,
Sept. 26, 1899.

THE WAVE-LENGTH OF THE GREEN CORONAL LINE, AND OTHER DATA RESULTING FROM AN ATTEMPT TO DETERMINE THE LAW OF ROTATION OF THE SOLAR CORONA.[1]

By W. W. Campbell.

A determination of the law of rotation of the solar corona would no doubt be valuable on many accounts. Interest in this problem was aroused by Deslandres' attempt to solve it at the 1893 eclipse, in Senegal. The reality of his result has been questioned on the ground that the H and K calcium lines, used by him, do not have their origin in the corona, but in the prominences and chromosphere. It seemed proper that another determination should be attempted, basing it upon light radiations which are of unquestioned coronal origin. Accordingly, as one of many problems, it was undertaken by the Crocker expedition[2] sent out from the Lick Observatory to observe the eclipse of January 22, 1898, in India.

It was evident that this investigation, involving the Doppler-Fizeau principle, and requiring high dispersion, could apply, with any hope of success, only to the bright-line portion of the corona. Existing data seemed to show that the green line and those near $\lambda\lambda$ 423 and 399 were the only reasonably strong and unquestioned coronal lines in the available portion of the spectrum; and further, that the photographic action of the green radiation was vastly stronger than in the case of the other two lines, even though the green line lay in a region of weakness on isochromatic plates. It was therefore decided to base the observations on the green line. The justification of this decision

[1] Read at the Third Conference of Astronomers and Astrophysicists, September 7, 1899.

[2] The expenses of the expedition were defrayed by the late Hon. C. F. Crocker, a regent of the University of California. He was also the patron of the expeditions to Cayenne (1889) and Japan (1896).

seems clear, in view of Newall's experience.[1] His ingenious and powerful apparatus was constructed for recording the blue line at λ 423; but his plate, on development, showed no trace of any impress of the coronal line.

Since prismatic dispersion in the green is relatively weak, the question of using a large-sized grating was considered. Two gratings with ruled surfaces about 2.5 × 3.9 inches were kindly loaned by Mr. Brashear; but some simple experiments indicated clearly that a large number of suitable prisms would be more efficient for this purpose than a grating, besides permitting greater compactness and stability of mounting.

The optical train of the instrument employed was as follows:

Image lens; clear aperture, $2\frac{1}{16}$ inches; focal length, $19\frac{7}{16}$ inches; forming an image of the Sun on the slit, with diameter 0.184 inch.

Collimator lens; clear aperture, $2\frac{5}{32}$ inches; focal length, $20\frac{3}{4}$ inches.

Four compound prisms, altitude of each, $2\frac{5}{8}$ inches; face, $2\frac{1}{8}$ inches; combined minimum deviation for λ 5317, 152° 37′.

Two single 60° prisms; altitude, $2\frac{1}{2}$ inches; face, $3\frac{1}{8}$ inches; combined minimum deviation for λ 5317, 113° 04′.

Camera lens; clear aperture, $2\frac{1}{2}$ inches; focal length, 20 inches.

The combined deviation of the six prisms being 265° 41′, the beam of light in the camera crossed the beam in the collimator nearly at right angles.

These optical parts were mounted in wood (Spanish cedar) from my drawings, by the Observatory carpenter, and finished in shellac. The instrument was easily adjusted, and worked well.

Immediately in front of the plate-holder were three rectangular sliding diaphragms for controlling the exposures. These could be withdrawn, singly, in a direction parallel to the Fraunhofer lines of the spectrum. One of these (A) covered the red end of the spectrum up to within $\frac{1}{4}$ inch of λ 5317. Another (B) covered the violet end up to within $\frac{1}{4}$ inch of λ 5317. A

[1] *Proceedings Royal Society*, **64**, 56, 1898.

third (C), about $\frac{5}{8}$ inch wide, covered the central half inch of the plate, overlapping (A) and (B) very slightly.

A Cramer isochromatic plate, backed with Carbutt's liquid backing, was employed.

The slit of the spectrograph was set at 0.04 mm and directed upon the solar equator. About 15 minutes before totality the red end of the plate was uncovered by withdrawing diaphragm A. The solar crescent was caused to drift rapidly along the slit, thereby recording the solar spectrum in the region A, for reference. Diaphragm A was inserted, and the polar axis was set in motion by the clockwork. Two seconds after totality, diaphragm C was withdrawn, allowing the region of the coronal spectrum between $\lambda\lambda$ 5260 and 5430 to record itself on the plate. The diaphragm was inserted at 1^m 52^s after the beginning of totality. After third contact, diaphragm B was withdrawn, and the solar crescent caused to drift along the slit, recording the solar spectrum on the violet end of the plate, for reference.

On developing the plate, in camp, the solar spectrum at the red end of the plate was found to be suitably exposed, whereas that at the violet end was underexposed — but measurable — probably on account of my underestimating the reduced brightness of the thin crescent. The continuous spectrum of the inner corona was strongly recorded, as was also one strong bright line. However, I was struck with the fact that the bright line fell much further to the violet side of the region uncovered by diaphragm C than I had expected. Being busy with further photographic developing, in the intense heat, the matter escaped my attention. While engaged in measuring this plate, in January 1899, I learned that Lockyer had assigned a new wave-length to the green coronal line. Reducing my measures, I at once obtained a result in substantial agreement with his.

The details of my determination of the wave-length are given below. The first column contains Rowland's wave-lengths of the solar lines used for reference. The second contains these wave-lengths corrected for the fact that the lines under diaphragm A had their origin at the E. (approaching) limb of the

Sun, and those under *B* had their origin at the W. (receding) limb. The micrometer readings on the solar lines, and on the bright lines, are contained in the third and fourth columns, the value of a revolution of the screw being 0.25 mm. The readings on the bright coronal line were made at points 2′ from the E. limb and 1′ from the W. limb.

Rowland's W.-l. in ⊙	Corrected W.-l. in ⊙	Micrometer measures E. of ⊙	Micrometer measures W. of ⊙	Computed W.-l.	
				E. of ⊙	W. of ⊙
5183.79	5183.83	12.162	12.062	5183.83	5183.83
5227 2^{4}	5227.2[1]	27.883	27.790	5227.26	5227.21
Bright	Line	53.176	53.185	5303.21	5303.32
5463.33	5463.29	98.908	98.957	5463.30	5463.36
5476.9^{4}	5476.9^{4}	102.402	102.427	5476.96	5476.90
5497.74	5497.70	107.603	107.650	5497.70	5497.70
5528.64	5528.60	115.137	115.177	5528.67	5528.60
5603.10	5603.06	132.161	132.226	5603.02	5602.95
5688.44	5688.40	150.080	150.152	5688.53	5688.38
5763.22	5763.18	164.441	164.562	5763.18	5763.18

The wave-length of the bright line was computed by means of Dr. Hartmann's exceedingly valuable interpolation formula,[2]

$$\lambda - \lambda_\circ - \frac{C}{R_\circ - R} = 0\,.$$

Substituting 5183.83, 5497.70 and 5763.18 successively for λ, and their corresponding micrometer readings for R, and solving for $\lambda_\circ$, C and $R_\circ$, there resulted,

$$\text{For E. side, } \lambda = 3805.43 + \frac{[5.850829]}{526.744 - R}\,;$$

$$\text{For W. side, } \lambda = 3806.57 + \frac{[5.850844]}{527.088 - R}\,.$$

Substituting the various values of R in these equations, and solving for λ, we readily obtain the wave-lengths in the last two columns of the table. The three wave-lengths on which the formula were based naturally reproduce themselves. The accordance

[1] A double line.

[2] This JOURNAL, **8**, 218, November 1898.

of the computed values of the wave-lengths with Rowland's values furnishes an indication of the accuracy of the results. No doubt a slight improvement of the residuals would have resulted from a least-square determination of the values of λ_0, C and R_0; but on account of the character of the bright line, to be described later, this would have been superfluous.

The wave-lengths obtained for the coronal line are

For E. side, 5303.21
For W. side, 5303.32
Mean, 5303.26

The difference of the determinations for the E. and W. sides is 0.11 t.m., corresponding to a relative velocity in the line of sight, for the two sides, of 6.2 km, or a rotational velocity of 3.1 km per second. However, I regard this last result as subject to a possible error of at least ± 2 km per second: partly on account of unavoidable errors of observation, but principally on account of the character of the bright line. The inner ends of the bright line are overexposed, while its outer ends are underexposed, and it does not seem to be monochromatic. The suitably exposed portions of the line are not only ill-defined, but unsymmetrical, and accurate settings on them could not be made. It is possible that the original radiations were reasonably monochromatic. A good photograph of the green coronal ring was secured with another of our instruments, an objective grating spectrograph, showing this ring to be extremely irregular in form; and I believe the observations by Lockyer, Newall and others led to the same conclusion. Such being the case, we should expect rapid movements to occur within this atmosphere. The recorded appearance of the line $\lambda 5303$ finds, possibly, an easy explanation in the distortions due to relative velocities, in the line of sight, of the different portions projected on the slit.

In planning the apparatus, it was taken for granted that this line would fall at $\lambda 5317$. Inasmuch as some of the earlier observers mention having seen one or two additional bright lines in this vicinity, the diaphragms were arranged so that one half inch of the plate was reserved for coronal exposure, hoping to

record any of these additional lines. This is responsible for the great distance between the bright line and the solar reference lines; and, besides, the whole purpose of the main problem was to measure *difference* of wave-lengths. Had it been intended to determine the wave-length of the green line, the comparison spectrum would have been arranged very differently. However, the above value of the wave-length should not be in error by more than ± 0.15 t.m.

As confirmatory of the above value, the green ring on the objective grating spectrograph, referred to above and to be described later, is at $\lambda 5303$.

It is desirable that the position of the line should be determined as accurately as possible at the next eclipse.

The radial length of recorded bright line at the E. limb is $4'$, and at the W. limb $2'$. It does not seem wise to attempt to measure the coronal rotation at the short eclipse of 1900, but it is possible that useful results might be obtained at the East Indian eclipse of 1901, lasting 6½ minutes.

The continuous spectrum of the inner corona was recorded out to a distance of $2.5'$ on the E. side, and of $1.5'$ on the W. side. The greater strength of coronal radiation on the E. side is very apparent for both bright-line and continuous spectra. While the dark lines in the recorded comparison spectra are sharp and strong, there is not the slightest trace of dark lines in the recorded continuous spectrum of the corona. This radiation seems to be of coronal origin, and not due to reflected photospheric radiations.

I do not think it is difficult to explain the origin of the error which has prevailed for many years in the accepted value ($\lambda 5316.87$) of the wave-length of the bright coronal line; and the following explanation is respectfully suggested.

The strongest chromosphere line in this region is the one at $\lambda 5317$. On one of my photographs, giving a continuous record of the spectrum of the Sun's edge, both when the thin crescent was gradually disappearing at contact II, and reappearing at contact III, the line $\lambda 5317$ is the brightest in this region, and

"persisted" slightly longest.[1] Likewise, in visual observations at contact II, it would no doubt be the brightest line visible, and "persist" longest. Inasmuch as my moving plate recorded many of the faintest chromosphere lines in Professor Young's list, but made no record of a bright line at $\lambda 5303$, it is pretty certain that the true coronal line would be difficult to observe so long as the chromosphere spectrum was visible. The observers made it their first duty to fix the position of the green line. The persisting chromosphere line, very conspicuous just before and at the instant of totality, was naturally assumed to be identical with the true coronal line, and its position was fixed at 1474K. Later, when this line had disappeared, rather suddenly, and the background had become dark enough to allow the line at $\lambda 5303$ to be seen, the observers were interested in determining the extent, and other allied properties, of this line; and no further micrometer settings were made for determining its wave-length. This illustrates one of the advantages of photographic methods, now happily available.

The photograph above described is not suitable for mechanical reproduction; but, with the Director's assent, I should be willing to supply copies on glass to those investigators who are planning for observations, based on the green coronal line.

Professor Young contributed largely to this determination of the position of the coronal line, by arranging for the most generous loan of the four large compound prisms, described above, and belonging to Princeton University; and also, by the fact that the instrument was manipulated during totality, in a perfectly satisfactory manner, by one of his former students in Dartmouth College, the Rev. J. E. Abbott, long a resident of Bombay, who extended many favors to the expedition.

LICK OBSERVATORY,
August 23, 1899.

[1] This persistence may be due to the greater brightness of the line, rather than to a thicker stratum.

THE RING NEBULA IN LYRA.[1]

By James E. Keeler.

On taking charge of the Crossley 3-foot reflector of the Lick Observatory, about a year ago, it was my intention to devote the instrument to spectroscopic work, for which a spectroscope, designed by Professor Campbell, had been partially completed by the Observatory instrument maker. It was first necessary to make numerous small changes in the mounting and in the guiding apparatus. The pier was also cut down two feet, and a new and powerful driving-clock was made at the Observatory from plans by Professor Hussey.

To test the capabilities of the instrument, a number of photographs were then made of well-known celestial objects, and these were of such excellence that I determined to pursue this photographic work for the present, and to put off the spectroscopic investigations until some future time.

Among the objects photographed was the ring nebula, which I have chosen for the subject of the present paper; not because it is specially well suited to display the capabilities of the telescope (for this is not the case), but because it is a very well-known object, to which observers, with photographic telescopes in particular, have paid a great deal of attention, and which possesses in itself many features of interest.

It is very doubtful whether the ring nebula in Lyra has ever been photographed with an entirely suitable instrument. In this connection it may be well to recall the fact that the focal length of a camera must be from thirty to sixty times its aperture in order that the photographic and optical resolving powers may be equal. A photograph taken with such an instrument, under perfect atmospheric conditions, should show all that the eye can see. Practically, however, mechanical difficulties of construction, and the faintness of the light emitted by some

[1] Read at the Third Conference of Astronomers and Astrophysicists, Sept. 7, 1899.

objects, make it necessary to modify the theoretical ratio of focal length to aperture. For photographing faint, diffuse nebulae, in particular, the focal length must be short.

In all modern reflectors the focal length is quite small for the aperture. But the ring nebula is photographically a bright object. It is also a small object ($80'' \times 60''$), and hence could be most advantageously photographed by a reflector of unusually great focal length.

In photographic refractors the ratio of focal length to aperture is usually much greater than in the reflector; but aside from the fact that the absolute focal length of such instruments is, in general, small, the absorption of the chemically active rays by the glass lenses is so great that the nebula can no longer be regarded as a bright object. Thus, I find that exposures of nine, and even up to twenty hours have been given to the ring nebula with refracting telescopes. With the Crossley reflector such exposures would yield nothing but a large black blotch on the negative.

The Crossley photographs.—As an example of the exposure-times required for the Crossley reflector, I give the following list of negatives made here under the finest conditions:

1899, July 13. Exposure two hours. All parts of the nebula greatly over-exposed, though the plate was treated for over-exposure.
July 12. Exposure one hour. Over-exposed.
July 14. Exposure thirty minutes. Good photograph; treated for over-exposure.
July 14. Exposure ten minutes. Best general picture of the nebula.
July 14. Exposure two minutes. Distinct image.
July 14. Exposure one minute. Faint image.
July 14. Exposure thirty seconds. Barely visible image.

The focal length of the Crossley telescope is seventeen and one half feet, and the longer diameter of the ring nebula on the plate is about 2 mm. If the focal length of the telescope were increased four times, the diameter of the image would be about 8 mm, and the length of exposure required would be about three hours, which is not excessive. With such an instrument a far better photograph could doubtless be obtained than any that has yet been made.

But it is impracticable to change the focal length of a telescope, while the aperture is easily varied. Considering the Crossley telescope, therefore, as an instrument of fixed focal length, the only advantages to be expected from reducing the aperture are (1) diminution of aberration, (2) diminution of atmospheric disturbance.

1. The aberration of a parabolic mirror has been discussed (among others) by Professor Schaeberle, who found it excessive at a short distance from the axis; but the case is not really so bad as he made it out to be, as may be shown by applying the more rigid methods of physical optics to the same problem. The excellent star images on Sir Isaac Roberts' photographs are a practical support of the above statement. With the Crossley reflector the star images are quite good one or one and one half inches from the axis, and at half an inch from the axis they are practically perfect. For such an object as the ring nebula the aberration is therefore insensible.

2. The photographs mentioned in the preceding list were taken on nearly perfect nights, when no improvement in the definition would have resulted from cutting down the aperture.

I have tried the Crossley telescope on objects still smaller than the ring nebula. A photograph of the planetary nebula *G. C.* 4628 ($26'' \times 16''$), taken on the night of July 30 with two minutes' exposure, shows the nearly circular outline, the distorted inner bright ellipse, and the central nucleus, almost exactly as drawn by Professors Holden and Schaeberle.[1] The exposure is about right. Another plate, to which was given an exposure of ten minutes, shows the projections or "ansae," strong at the outer ends, and faintly connected with the main nebula, which is greatly over-exposed. For such objects, however, visual observation with the 36-inch refractor is more satisfactory than photography.

The photographs of the ring nebula made with the Crossley reflector show features which have been described by observers with powerful visual and photographic telescopes, and others of which I can find no description and which appear to be new. In

[1] *Monthly Notices*, **48**, Plate 4.

this connection I have consulted a large number of papers on the nebula, and such drawings and photographs as have been published and are in our library. I have also re-observed the nebula with the 36-inch refractor of this Observatory.

The most satisfactory drawing is one made by Professor Holden at Washington in 1875. The original is at the Lick Observatory. Trouvelot's drawing in *H. C. O. Annals*, Vol. VIII, is also excellent. Neither drawing shows the central star, and both are somewhat too regular and symmetrical.

Form of the nebula. — The outline of the ring nebula, as shown by the Crossley photographs, is oval rather than elliptical, the more pointed end being toward the northeast. M. Stratonoff's diagram in *A. N.*, 3388 shows the form well, though the inner dark space is, owing to the long exposure and the spreading of the photographic image, considerably too small. From both sides of the oval project faint masses or fringes of nebulosity, much as drawn by Lord Rosse,[1] but less uniform in shape and brightness, and having no structure. The most important of these projecting nebulosities are tabulated below, the position angles being measured from the central star as center. Not having made trails on any of the plates, I take the position angle of the bright star following the nebula to be 87.8°, as determined by Professor Burnham.[2]

Projection.	Limiting pos. angles	Projection beyond ellipse.
a	7°– 27°	2″
b	31 – 52	10
c	60 – 82	5
d	88 –102	3
e	138 –178	4
f	195 –222	11
g	222 –240	5–0
h	240 –260	7
i	270 –276	2
j	281 –292	2
k	345 – 0	4

[1] *Phil. Trans.*, 1844, Plate 19, Fig. 29.

[2] *Monthly Notices*, **52**, 42.

The projection *e* is so much brighter than the others that it is perhaps to be regarded as a part of the nebula proper, rather than as attached nebulosity. Without it the outline of the nebula would be much nearer to a true ellipse.

Structure of the ring. — The ring, as shown in these photographs, has a quite complicated structure. It seems to be made up of several narrower bright rings, interlacing somewhat irregularly, the spaces between them being filled wiih fainter nebulosity. One of these rings forms the outer boundary of the preceding end of the main ring. Sweeping around to the north end of the minor axis it becomes very bright, perhaps by superposition on the broader main ring of the nebula at this place. It crosses this ring obliquely, forming the brightest part of the whole nebula, and then forms the inner boundary of the main ellipse toward its following end. The remaining part of the ring is not so easily traced, as several other rings interlace on the south side of the ellipse. One of these forms the projecting arc *e* already referred to, and then, crossing the main ring obliquely, it forms the inner boundary of the ellipse on the north side.

The main ring contains many bright patches and condensations, but I find no evidence in my photographs of general resolution into detached knots of nebulosity, such as Denza thought he had observed.

Dimensions of the nebula.— When an object is, like this, not sharply bounded, but fades outward somewhat gradually into the sky, its dimensions determined from a photograph must depend upon the length of exposure given to the negative; further, and for the same reason, its dimensions determined by visual micrometer measures must depend to some extent upon the aperture of the telescope employed. It is also possible that the exterior fringes of nebulosity may, like the outlying streamers of the nebula of Orion, emit chiefly the hydrogen radiations, in which case they would be visually weak and photographically strong. The photographic image would then be larger than the visual. In the case of a photograph taken with long exposure, the

image may also exceed its proper dimensions by the spreading of the photographic action.

In *A. N.*, 3354, Professor Barnard has given his measures of the ring nebula with the Lick telescope, and in *A. N.*, 3388, M. Stratonoff has compared these measures with his own, made on photographs taken with a refractor of 0.33 m aperture. I give these results below, together with my own. It will be seen that the dimensions determined by photography are, in general, larger than those obtained visually.

	Barnard (36 in. visual.	Stratonoff (phot. 10 h.)	Keeler (phot. 10 m.)
Major axis outside ellipse - -	80.89"	90.19"	87.3"
Major axis inside ellipse - -	36.52	29.13	40.8
Minor axis outside ellipse (extreme)		63.11	63.9
Minor axis outside (mean) ellipse	58.81		58.6
Minor axis inside ellipse - -	29.36	24.52	32.0

I have assumed that Barnard placed his micrometer wire tangent to the mean ellipse, in measuring the length of the minor axis outside. Stratonoff, with his long exposure, certainly measured the extreme diameter, *i. e.*, to the outside of the projection *e* of my table. His plate with 20^h exposure shows a still greater divergence from the visual measures. The irregularities of the outlines, and the somewhat gradual fading of the light, make the measures of my plates somewhat uncertain, though the definition is excellent.[1]

Structure of the interior space.—Lord Rosse's drawing in the *Phil. Trans.*, 1844, shows the interior space of the nebula crossed by a series of dark and bright bands in the direction of the major axis, and this drawing has, I think, generally been regarded as fanciful. Nevertheless, the structure it represents is confirmed by the Crossley photographs, and confirmed, so far as I am aware, for the first time.[2] There are, however, only three dark and two bright bands within the ellipse, unless the

[1] On the plate with 10 m exposure the disks of stars 3" apart are clearly separated.

[2] PROFESSOR HOLDEN'S partial confirmation with the Washington telescope was subsequently regarded by himself as probably a mistake. *Mon. Not.*, **48**, 384, 1888.

nebulous border around the inner edge of the ring is regarded as constituting two more of the latter. One of the dark bands is centrally placed. The central star is not precisely on the middle line of this band, but a little nearer the north edge. The direction of the bands is not exactly that of the major axis of the nebula, but in a position angle about 5° greater. At the following end of the interior ellipse the nebulosity is brighter, as described by Holden and illustrated in his diagram (*Monthly Notices*, **48**, 386), forming a bright patch without definite outlines. The bright bands become fainter toward their intersection with the minor axis. It is quite probable that on photographs of still better definition, this band-like appearance would be resolved into a more complex structure, to which it is perhaps only incidental.

I have tried to verify this band structure of the photographs by visual observation with the 36-inch refractor, and have fancied that at times I could catch glimpses of it; but the observation is a most difficult one. The image as seen in the telescope is sufficiently large, bright, and well defined, but the contrast of the light and dark bands, which is exaggerated by the photograph, is almost too slight to affect the eye.

The central star.—The actinic power of the central star[1] of the ring nebula has been remarked by many observers. My own photographs also demonstrate this peculiarity of the star, for it is perfectly distinct on the plate taken with an exposure of one minute, and is faintly visible on the plate exposed for thirty seconds. But a more careful study of my negatives shows that the actinic power is less remarkable than I had at first supposed it to be. Other stars, which have never been regarded as possessing any unusual properties, are also strongly impressed on plates with short exposures.

On plates to which long exposures were given, the central star is just about equal to Lassell's star 3, outside the ring. With shorter exposures the superiority of the central star becomes apparent, and on the plate exposed two minutes the

[1] Estimated by Burnham as 15.4 visual mag. *Mon. Not.*, **52**, 42.

comparison star is no longer visible, while the central star remains. The difference is however, not very striking.

I may note here that the strength of the central star relatively to that of the nebula depends upon the nature of the photographic instrument employed ; the brightness of the star follows one law, that of the nebula another. This relative brightness, therefore, considered by itself, has little physical meaning.

From observations made in 1891 with the 36-inch refractor, I concluded that, as in an ordinary star, the maximum intensity of the light in the spectrum of the central star of this nebula falls in or near the yellow. The spectrum itself is too faint for observation, and the above conclusion rests on the fact that the nebula is best seen with the eyepiece drawn out a little from the position which gives the most distinct vision of the central star.[1] The nuclei of planetary nebulae, have, according to Scheiner,[2] the same remarkable actinic power as the central star of the ring nebula ; nevertheless, in the spectra of these stars, many of which could be observed with the Lick spectroscope, the maximum brightness was found to be in the yellow region. I have suggested in my memoir on the spectra of the nebulae, in Vol. III of the *Publications of the Lick Observatory*, that the photographic strength of these central stars may be due to bright lines in the upper spectrum (very probably the ultra-violet hydrogen series). With suitable apparatus, which is in preparation, I anticipate no difficulty in photographing the spectrum of the central star of the ring nebula. The results, if successful, can hardly fail to throw light on the particular question involved, and indeed on the whole question of stellar evolution.

On all of my photographs the central star is as clearly defined as are other stars outside the nebula ; there is no evidence of blending into the nebulous background. This is also the appearance of the star as seen with the 36-inch refractor.

Other stars in the nebula.—Besides the central star, only one other star is shown on the photographs within the darker

[1] *Publications of the Lick Observatory*, **3**, 210.

[2] *A. N.*, 3086. See also my own photographic observations of *G. C.* 4628 above.

PLATE IX.

RING NEBULA IN LYRA. EXPOSURE 2^h.
Photographed with the Crossley Reflector of the Lick Observatory.

PLATE VIII.

RING NEBULA IN LYRA. EXPOSURE 30^m.
Photographed with the Crossley Reflector of the Lick Observatory.

PLATE VII.

RING NEBULA IN LYRA. EXPOSURE 10^m.
Photographed with the Crossley Reflector of the Lick Observatory.

space enclosed by the ring. Its position with reference to the central star is

$$p = 297^\circ \qquad d = 10.7''.$$

It is evidently the star *d* of Holden's diagram.[1] This star is very distinct on the negative made with 10 m exposure, and is just visible on that exposed for 2 m. As it is at the very limit of vision with the 36-inch refractor, it must, like the central star, possess unusual photographic energy.

Holden's star *f*, at the preceding extremity of the major axis, also appears on the photographs. On some of the plates it is larger than other stars of the same magnitude, and slightly irregular, so that it is perhaps not a true star, but a very small bright patch of nebulosity. The other stars of the diagram seem to be bright patches due to the interlacing of the narrow rings, but in such cases as this the evidence of the visual telescope is perhaps to be preferred.

Barnard's small nebula.—The negative obtained with two hours' exposure shows that the small nebula discovered by Professor Barnard[2] with the 36-inch refractor in 1893 is a left-handed, two-branched spiral. The extreme diameter on the photograph is about 30.

The positive enlargements (11.1 diameters, 1 mm $= 3.55''$), sent with this, in the form of lantern slides, reproduced in Plates VII, VIII, and IX, show most of the details described in the foregoing article.

In all work with the Crossley reflector I have had the efficient assistance of Mr. H. K. Palmer, Fellow at the Lick Observatory.

LICK OBSERVATORY,
August 15, 1899.

[1] *Mon. Not. R. A. S.*, **48**, 386.

[2] *A. N.*, **134**, 130, 1893.

PRESSURE IN THE ELECTRIC SPARK.

By John Fred Mohler.

In an article published in the Astrophysical Journal for June 1899, Eduard Haschek and Heinrich Mache give a method by which they obtain the amount of pressure produced when a spark is passed through a gas. They give results for various media, for different electrodes, and for variation of capacity, spark length, and pressure of the surrounding media.

The work touches some done by Dr. Humphreys and myself[1] in that we have found that when the arc is under pressure the period of vibration of the light emitted is a little greater than when the pressure is removed, and consequently the wave-length is increased a little when pressure is added. We have shown in the article referred to above that this change in wave-length or shift of the spectral lines is proportional to the pressure, and in some cases to wave-length, and that it varies with the element producing the line.

The measured shift of the lines of a few of the elements under twelve atmospheres pressure, together with the shift reduced to wave-length 400, is given in the following table:

	Wave-length	Measured shift	Reduced shift
Cadmium - -	4678.389	0.092	0.080
" - -	4800.097	.096	.080
" - -	5086.001	.106	.080
Iron, average of lines		.025	.025
Zinc, average of lines		.057	.057

Using these data as a starting point it would seem possible to measure the pressure at the source of light if we knew the displacement of the lines. This assumes that a spectral line will be displaced by pressure whatever may be the source of light producing the line. The question of the amount of pressure becomes very interesting in the light of the recent experiments

[1] This Journal, 3, 114, 1896; also 4, 175, 1896.

of Professor J. Wilsing,[1] who obtained a spectrum very similar to that of the new stars by passing a spark between electrodes immersed in water.

My experiments described below were made to test the results obtained by Haschek and Mache. If their results are near the truth the shift of the lines due to pressure should be very considerable; indeed, as in many experiments they found a pressure of more than fifty atmospheres, the shift of the lines should be four or five times the largest shift we found in previous experiments with the arc, and the displacement due to one atmosphere is a measurable quantity with some elements.

I used in this investigation a four-inch concave Rowland grating, mounted in the usual way on piers of solid masonry, in a room of nearly constant temperature. Photographs of the spectrum under consideration were taken along with the spectrum of the arc, at atmospheric pressure, for comparison. The camera was very solidly mounted and the plate was exposed to the arc spectrum both before and after it was exposed to the spark. For varying the pressure around the spark and for investigating the effect of different gases the electrodes were inclosed in a heavy brass vessel similar to that used in the previous work.[2] This vessel was mounted with the arc lamp on a swinging frame, so arranged that either spark or arc could be focused on the slit of the spectroscope without touching the mounting of the grating. For capacity I used a series of jars, some large and some small. Their capacity was not very accurately determined, but the error cannot be more than 4 or 5 per cent. The induction coil used was capable of giving an eight-inch spark when used without capacity. The spark gap was usually 3 mm or less. A filar micrometer in connection with a very low power microscope was used to measure the displacement of the lines. As the previous work had shown that cadmium gives a relatively large displacement under pressure I used that metal in most of my experiments.

[1] *Sitz. d. K. Akad. d. Wis. zu Berlin*, No. 24, May 4, 1899; this JOURNAL, **10**, 113, 1899.

[2] This JOURNAL, **3**, 116, 1896.

CAPACITY.

Messrs. Haschek and Mache found that under given conditions the pressure produced when the spark is passed through air varied with the capacity in a peculiar way. As the capacity increased the pressure increased to a maximum of fifty-one atmospheres and then decreased. Below is part of their table giving the relation of capacity to pressure:

Capacity in meters	Pressure in atmospheres
5.16	22
11.1	40
22.9	45
53.1	51
100.2	46
156.	36

With cadmium electrodes and at atmospheric pressure I found the displacement of the green and blue lines with varying capacity to be as given in the following table. The measured shift is given in thousandths of an Ångström unit, the capacity is given in meters. Considering 0.008 as the measured shift of the cadmium lines per one atmosphere pressure, I give in the same table the pressure in atmospheres deduced by this method.

Wave-length	Capacity	Shift	Pressure
5086.001 4800.097 4678.339	11.1	0.026	3.25
4800.097 4678.339	22.2	0.036	4.5
4800.097 4678.339	22.2	0.052	6.5
4800.097 4678.339	48.	0.084	10.5
4800.097 4678.339	70.2	0.088	11.

The above table shows that the pressure calculated from the shift of the lines is very much smaller than that given by Haschek and Mache. Considerable allowance must be made for errors in measurement of the shift, as the spark lines, with condensers in the circuit, become broader as the capacity is increased.

The last result with capacity of 70.2 meters gives but a slightly greater shift than a capacity of 48 meters. This seems to indicate that the pressure does not increase directly with capacity, but as indicated by Haschek and Mache, the pressure approaches a maximum value.

The effect of capacity on the position of the iron lines of the spark spectrum was also investigated. With small pieces of steel as electrodes several photographs were taken with a capacity of 22.2 meters. About twenty lines on these plates were measured. The shift was small, and the average measured displacement was 0.011 Ångström unit. The previous work indicated that the shift per atmosphere was about 0.002 Ångström unit for the iron lines. This would indicate a pressure in the spark of 5.5 atmospheres which is the average found for cadmium for the same capacity.

PRESSURE.

The effect of the pressure of the surrounding medium is shown by comparing the shift produced by the spark with a definite capacity when the pressure about the electrodes is one atmosphere with the shift produced when the pressure is four times as much, the capacity remaining the same. The capacity used for this experiment was 22.2 meters. The pressure was four atmospheres and the measured shift was 0.160 Ångström unit, corresponding to a pressure in the spark of 20 atmospheres. This, compared with the shift at atmospheric pressure, shows that the pressure in the spark varies very nearly with the pressure of the surrounding medium. This is altogether different from the results given by Haschek and Mache, who find that the pressure in the spark increases very much faster than the pressure in the surrounding medium.

The effect of the kind of gas surrounding the electrodes as given by Haschek and Mache indicates that carbon dioxide had three times the effect of atmospheric air, and strangely enough, illuminating gas with a density of 0.47 had produced a greater pressure than air.

The results of my experiments to test this point are given below. The measurements were made on the two blue cadmium lines of wave-length 4800.9 and 4678.3.

Capacity	Shift, CO_2	Pressure, CO_2	Pressure, air
22.2	0.067	8.4	5.5
48.	0.116	14.5	10.5

This gives an average ratio of the effect of carbon dioxide to that of air of 1.45 instead of 3.

The above results show, I think, that there is pressure produced when the spark passes through a medium, but that it is not nearly so great as supposed from the work of Haschek and Mache. These results also show that the amount of pressure varies with the density of the medium surrounding the electrodes, and that the kind of gas does not affect the result. With a medium such as water, 800 times as dense as air, with a small capacity (say one meter) a displacement of about 0.4 Ångström unit would be produced in the iron lines, which is only a little less than the average displacement of the lines obtained by Professor Wilsing.

Dickinson College,
Aug. 30, 1899.

Minor Contributions and Notes

ON TITANIUM FOR A COMPARISON SPECTRUM.

In the preliminary observations for determining the radial velocities of stars with the spectrograph attached to the forty-inch refractor of the Yerkes Observatory, the spark between iron electrodes was employed as the source of the comparison spectrum. The spark apparatus was swung into place in the collimation axis of the refractor, and a brief exposure given to the spark either before and after or at the middle of the exposure to the star, according to the duration of exposure required for the star. The region of spectrum brought to the center of the plate was about $\lambda 4600$. The iron comparison spectrum proved, however, to be rather unsatisfactory on account of a scarcity of good lines in the spark in this region, and on account of the troublesome air lines which are here numerous and broad, obscuring some of the fainter iron lines. In looking about for some other element to substitute for iron, I decided that titanium ought to give satisfactory results. On obtaining metallic titanium, through the courtesy of Professors Smith and Lengfeld, of the chemical department of the University, I was gratified to find that the spark gave a large number of very sharp lines, very uniformly distributed throughout the spectrum from λ 4200 to λ 5000, and free from air lines. The spark passes much more steadily between titanium electrodes than in case of iron, and considerably shorter exposures are required — less than ten seconds as the apparatus is usually arranged. The consumption of the element is very slight, and it is only necessary to occasionally brighten up the points of the electrodes.

The wave-lengths of the lines in the titanium (arc) spectrum have been very accurately determined by Hasselberg,[1] and many of the lines are identified in Rowland's table of solar spectrum wave-lengths.

In stellar spectra of the solar type numerous coincidences can therefore be obtained, and the direct displacements of the star lines can be measured. When the wave-lengths of the comparison lines are

[1] This Journal, 4, 116, 212, 1896.

accurately known, however, it is not important that direct displacements should be employed, and I have commonly selected the best star lines, and measured their position with respect to the nearest titanium lines, which are seldom more than five tenth-meters distant. The scale value, $\frac{d\lambda}{ds}$, at any point in the spectrum can be very accurately calculated from Hartmann's convenient interpolation formula.

In spectra of Type I*b* it happens that almost every important stellar line falls very close to a sharp titanium line. In spectra of Type I *a*, measures of the broad and difficult hydrogen lines are not commonly necessary, only the finer lines being employed.

In the procedure which I have adopted for the reduction of stellar plates for radial velocity, no auxiliary solar plates are employed, and every plate is reduced independently of all others. It is believed that in this way errors due to differences of dispersion and of camera focus, etc., on account of temperature, can be avoided, and the danger of systematic error somewhat diminished.

It is evident that the wave-lengths of unidentified stellar lines can be sharply determined throughout the whole region of spectrum on a plate, thanks to the uniform distribution of the comparison lines.

EDWIN B. FROST.

NOTE ON THE POSITION OF THE MAXIMUM IN THE SPECTRAL ENERGY-CURVE OF A BLACK BODY.

THE researches of Paschen on the spectrum of the ideal black body recently completed, which have been brought before the readers of the ASTROPHYSICAL JOURNAL in the articles by Paschen and by Paschen and Wanner in the June and May numbers, need no indorsement from me. They bear on their face the evidence of minute care, and are a brilliant confirmation of the remarkably simple law which now reads:

$$\lambda_{\text{max.}} \times T = 2891.$$

A few words in regard to the bearing of these results upon the objections urged by me against the proposed law (this JOURNAL, **2**, 316, November 1895; **4**, 38, June 1896) may be in order.

It will be evident that the law may be departed from rather widely

in the spectra of bodies which do not conform to the ideal of blackness. Moreover the definition of what constitutes blackness needs to be more exactly stated. For absorption, it is sufficient to say that the ideal black body must completely absorb rays of every wave-length, and this ideal appears to be very nearly fulfilled by a bolometer strip, coated thickly with soot and platinum-black in successive layers, and placed at the center of a reflecting hemisphere, pierced centrally by a minute window through which the rays pass, falling normally upon the blackened strip; but the perfect radiator is not so easy to obtain or define. Bodies whose spectral energy-curves have nearly the same form, and which will be called black if the relative emission of rays of different wave-lengths according to a special law is made the criterion of blackness, exhibit wide divergence in total emissive power, and this because the rate of emission depends not merely on the nature of the surface, but also on the conductivity of the underlying substance, and the readiness with which it transmits radiation from interior layers. If the blackest body is one which transfers the greatest amount of energy through the unit of surface in the unit of time by the radiative process, it is conceivable that this position may be taken by a body having a spectral energy-curve very different from that of lampblack, or other substances which have been arbitrarily assumed as standards. A further difficulty is the practical one that no single substance is available, or convenient, as a radiator through the entire range of temperature.

Assuming for the present purpose that blackness of a radiator means conformation to a spectral energy-curve which is very nearly that of lampblack or platinum-black, it appears probable that this standard is approximated by many other substances, at least within a middle range of temperature.

For the incandescent carbon of the electric arc-light, the formula gives:

$$\lambda_{\text{max.}} = \frac{2891}{3900} = 0.74^{\mu}$$

In an article by Captain Abney and Colonel Festing on "The Influence of Water in the Atmosphere on the Solar Spectrum and Solar Temperature" (*Proc. Roy. Soc.*, **35**, 328, 1883), is a spectral energy-curve of the positive pole of an electric arc (Diagram II, p. 334) which I overlooked when writing my former articles. The maximum is at about

0.73μ, agreeing well with that deduced by Paschen's law. I presume that the spectrum of the arc-carbon which gave a maximum near $1.1\ \mu$, must have been too impure for establishing this position, but it is no longer necessary to discredit the measurements of the temperature of the arc-carbons in order to fulfill the requirements of the law of the maximum.

Comparing the values of the position of the normal maximum, given in my former paper, with those obtained from Paschen's law, the following differences are found:

T (Absol.) -	1088°	798°	603°	451°	392°	313°
$\lambda_{max.}$ ($V.$) -	3.96^μ	4.55^μ	5.24^μ	6.20^μ	6.80^μ	8.04^μ
$\lambda_{max.}$ ($P.$) -	2.66	3.62	4.80	6.41	7.38	9.24
Diff. ($V.-P.$) -	+1.30	+0.93	+0.44	−0.21	−0.58	−1.20

Two causes conspire to produce these differences. (1) The imperfect absorption of long waves by the simply blackened bolometer makes the wave-length of the apparent maximum too small, and this to a greater degree as the temperature is lower and the maximum in the spectrum nearer to these long waves whose absorption by the blackening substance becomes less and less as the wave-length increases. (2) The temperatures of thick radiating plates are estimated too high, on account of neglecting the sub-surface temperature-gradient which is larger and increases the assigned maximum more, the higher the temperature. The first of these causes of error is eliminated in Paschen's recent work by the use of what may be called a repeating bolometer, in which the strip has repeated opportunities for absorbing the reflected remnant of radiation; and the second has been obviated by the use of radiant cavities and extremely thin radiant strips, reducing the sub-surface gradient to a minimum.

The second cause of error does not seem to apply to the radiating surface of an electric arc carbon, at least provided the voltage of the current is high, and the section of the carbon small enough to secure the conditions conducing to constant temperature.

It is to be hoped that Professor Paschen will give us the ratio of radiations of every wave-length, as measured by the repeating and the ordinary bolometer, in order that observations made with the latter may be reduced to the standard of the ideal black body.

FRANK W. VERY.

THE THIRD CONFERENCE OF ASTRONOMERS AND ASTROPHYSICISTS.

At the Second Conference of Astronomers and Astrophysicists, held at the Harvard College Observatory in August 1898, a committee, consisting of Professors Newcomb, Comstock, Pickering, Morley, and Hale, was appointed to make arrangements for a third conference, and to draw up a constitution for a permanent organization. This committee was given power to add to its number, and accordingly Professors Boss, Michelson, Langley, and Ames were requested to serve with the members already appointed. A meeting of the committee was held in Washington in February 1899, and a constitution was drawn up. It was decided at that time to hold the next conference at the Yerkes Observatory. Details of the arrangements were left to Professor Comstock, secretary of the committee, and to the Director of the Yerkes Observatory.

The conference opened its session at the Yerkes Observatory on September 6, 1899, with Professor Harkness in the chair. The following papers were read:

A. S. Flint, The Repsold Transit Micrometer of the Washburn Observatory and Slat Screen Apparatus.

S. J. Brown, The Position of the Axis of Neptune from Perturbations of its Satellite.

E. E. Barnard, Notes on the Annular Nebula in Lyra, the Fifth Satellite of Jupiter, Triangulation of Star Clusters, and Measures of the Difference of Declination of the Stars Atlas and Pleione.

William Harkness, On the Semi-Diameters of the Sun and Moon.

F. R. Moulton, Problems in Modern Celestial Mechanics Treated by the Use of Power Series.

Ormond Stone, On the Motion of Hyperion.

E. C. Pickering, The Revised Harvard Photometry.

Kurt Laves, Determination of the Principal Term of Nutation from Observations of Eros.

W. W. Campbell, Wave-Length of the Green Coronal Line.

Asaph Hall, Jr., Aberration Constant from Meridian Zenith Distances of Polaris.

J. E. Keeler, The Ring Nebula in Lyra.

George E. Hale, Notes on Carbon in the Chromosphere, the Connection between Stellar Spectra of the Third and Fourth Types, and Some New Forms of Spectroheliographs.

E. B. Frost, Notes on the Reduction of Stellar Spectra, Titanium as a Comparison Spectrum, and Corrections of Absolute Wave-Lengths due to the Earth's Motion.

Frank Schlesinger, Suggestions for the Determination of Stellar Parallax by Means of Photography.

S. I. Bailey, Note on the Relations between the Visual and Photographic Light Curves of Variable Stars of Short Period.

S. I. Bailey, The Periods of the Variable Stars in the Cluster Messier 5.

H. S. Davis, A Statement of the Progress of the New Reduction of Piazzi's Meridian Circle Observations between 1792 and 1814.

W. W. Campbell, The Spectroscopic Binaries Capella and Polaris.

F. L. Chase, Refraction of Red Stars.

George C. Comstock, Some Researches in Stellar Color.

Kurt Laves, Inner Potential Forces Applied to Celestial Mechanics.

F. R. Moulton, Laplace's Ring Nebular Hypothesis.

G. W. Hough, On the Actinism or Photographic Power of the Moon in a Total Eclipse.

M. B. Snyder, The Phonochronograph and its Advantages in certain Astronomical Observations.

Abstracts of all these papers will be published in *Science*, and most of the astrophysical papers will be published in full in this JOURNAL.

Several committees appointed at the Harvard Conference presented reports. The committee on a permanent society offered the following constitution, which was adopted without material change:

CONSTITUTION.

Article I. *Name and Purpose.*

1. This association shall be called The Astronomical and Astrophysical Society of America.

2. The purpose of this society is the advancement of astronomy, astro physics, and related branches of physics.

Article II. *Membership.*

1. Those persons whose names were signed on or before September 15, 1899, to the annexed statement of desire to form such an association shall constitute the charter members of this society. Other persons may be elected to membership in the society by the council hereinafter provided.

2. The council shall prepare and publish, in the form of a by-law, uniform rules for the government of such elections.

Article III. *Officers.*

1. The officers of the society shall consist of a president, two vice presidents, a secretary, and a treasurer, who, in addition to the duties specifically assigned them by this constitution, shall discharge such other duties as are usually incident to their respective offices. These officers, together with four other members of the society, shall constitute a council, to which shall be entrusted the management of all affairs of the society not otherwise provided for. The president and secretary of the society shall serve respectively as chairman and secretary of the council, and every officer of the society shall be responsible to the council and shall administer his office in accordance with its instructions.

2. The council shall enact such by-laws as may be found needful and proper for administering the affairs of the society, and may, from time to time, modify or repeal such by-laws.

3. The president, the vice presidents, and the treasurer shall be elected annually, in a manner to be prescribed by the council, and shall serve until their successors are duly elected and qualified. Two members of the council shall be chosen at the first annual meeting of the society to serve for a period of one year, and two members shall be chosen annually to serve for a period of two years, or until their successors are duly elected and qualified. The term of office of the secretary shall be three years, or until his successor is duly elected and qualified.

Article IV. *Meetings.*

1. The council shall determine the time and place of each meeting of the society, and shall provide for an annual meeting, at which officers shall be elected.

2. The council shall have charge of the program for each meeting.

3. At meetings of the society, regularly called, twenty members shall constitute a quorum.

Article V. *Finance.*

1. The council shall levy an annual assessment upon the members of the society sufficient to provide the funds required by the society for the ensuing year; provided that this assessment shall not exceed the sum of five dollars per member in any year.

2. If at any time there shall be required, for the purpose of the society, a larger sum than can be obtained in accordance with section 1 of this article, the council shall present at an annual meeting of the society a statement of such need, and of the circumstances attending it, and the society shall thereupon determine by ballot a policy to be adopted in the matter.

3. No officer of the society shall receive any compensation for services rendered to it, but the council may by resolution direct the treasurer to

reimburse to any officer expenses necessarily incurred by him in the discharge of his official duty.

Article VI. *Amendments.*

1. This constitution may be amended by the affirmative votes of three fourths of the members present at any annual meeting of the society, but no amendment shall be voted upon unless a notice setting forth the nature of such proposed amendment shall have been forwarded to the several members of the society at least one month before the meeting at which it is proposed to be voted upon.

2. It shall be the duty of the secretary to forward such notices of a proposed amendment to this constitution when so requested in writing by ten members of the society.

A by-law subsequently adopted by the council provides that

Any person deemed capable of preparing an acceptable paper on some subject of astronomy, astrophysics or related branch of physics may be elected by the council to membership in the society upon nomination by two or more members of the society. At least once in each year the council shall consider all such nominations and may request the opinion of persons not members of the council with reference to the qualifications of the nominees. Blanks for such nominations to membership shall be furnished by the secretary.

It was decided that officers of the new society should be elected on the last day of the session, and the committee on organization was instructed to take nominating ballots on the afternoon of the previous day. The results were announced at the final session on Friday morning, when officers of the Astronomical and Astrophysical Society of America were elected as follows:

OFFICERS.

President	Simon Newcomb.
Vice Presidents	C. A. Young, George E. Hale.
Secretary	George C. Comstock.
Treasurer	C. L. Doolittle.
Councilors, for two years	E. C. Pickering, J. E. Keeler.
Councilors, for one year	E. W. Morley, Ormond Stone.

On account of the poor health of Professor Comstock, Professor E. B. Frost, of the Yerkes Observatory, has consented to serve as acting

secretary for the present. The list of the charter members of the new society includes one hundred and fourteen names.

At a meeting of the council held on September 8, it was decided that the next meeting of the society should be held in June 1900, at New York, in conjunction with the meeting of the American Association for the Advancement of Science.

The committee on the total solar eclipse of May 28, 1900, consisting of Professor Newcomb, chairman, Professor Hale, secretary, Professor Barnard and Professor Campbell, presented the following preliminary report:

THE TOTAL SOLAR ECLIPSE OF MAY 28, 1900.

The committee on the total solar eclipse of May 28, 1900, appointed at the Second Conference of Astronomers and Astrophysicists, presents herewith a preliminary report.

The aim of the committee has been:

1. To ascertain the opinions of astronomers regarding the best means of securing coöperation, the most important classes of observations and the best means of making them, and the plans of the various eclipse parties.

2. To collect other information likely to be useful to persons planning to observe the eclipse.

For the purpose of securing information on the various points referred to in paragraph (1) a circular letter was addressed to American astronomers. From an examination of these replies it appears:

1. That there is a general willingness to coöperate with the committee in securing thorough observations of the eclipse phenomena and effective distribution of stations along the line of totality.

2. That, in the opinion of those from whom replies were received, the most important observations include studies of the minute structure of the corona, both visually and by means of large scale photographs; photography of the flash spectrum and determination of the wave-length of the green coronal line; measurement of the heat radiation of the corona; photographic search for an intra-mercurial planet.

3. That several institutions, including the Princeton, Lick, Naval, Goodsell, Chabot, Flower and Yerkes Observatories, will probably be represented by well-equipped parties; while a considerable number of astronomers with good instrumental equipment will take part as individuals.

4. That no general appeal to the public for funds is required, as each institution will endeavor to secure the amount necessary for its work.

5. That the work already planned includes observations of contacts, photography of the corona with large and small cameras; visual and photographic observations of the spectrum of the Sun's limb and of the corona;

visual examination of the details of the coronal structure; measurement of the brightness of the sky at different distances from the Sun; search for an intra-mercurial planet; observations of the shadow bands.

Extracts from the letters of various astronomers are appended to this report.

A preliminary report on the weather conditions along the line of totality has been prepared by the Weather Bureau, at the request of the committee (p. 221). From this it appears that interior stations are probably to be preferred to those on the seacoast, in spite of the shorter duration of the total phase. The full report of the Weather Bureau, which will soon be published, will contain much valuable matter, including maps of the eclipse track, showing location of towns and railways; information regarding hotel accommodations, desirable sites; etc.

It is understood that the Naval Observatory will issue instructions to observers, and that a map of the eclipse track will be published by the Nautical Almanac Office. The Treasury Department has made arrangements by which the instruments of foreign parties will be admitted free of duty.

The committee, if authorized by the conference to continue its work, will be glad to receive and publish further information from eclipse parties regarding their plan of observations and location of stations.

In response to the circular letter referred to above the committee has received the following statements regarding the classes of observations which are considered most important.

Ordinary photographs of the corona with cameras of different kinds; photographs with the apparatus designed by Mr. Burckhalter. (I am convinced from an examination of the photographs secured by this method in India, that such photographs show the forms of the coronal streamers far more satisfactorily than a comparison of ordinary photographs taken with different exposures.) Photographs for determining the exact wave-length of the "coronal line." It appears that this line has been erroneously identified with a line in the solar spectrum. Possibly, photographs for showing the displacement of this line on opposite side of the Sun, like those made by Deslandres, though very effective apparatus will be required for this purpose. Photographs of the spectrum of the "reversing layer." In my opinion the best form of instrument for this purpose is an object-glass spectroscope, arranged as follows: the refracting edge of the prism is placed parallel to the disappearing limb of the Sun. At the focus is a fixed slit, placed radial or lengthwise of the spectrum, and the photographic plate below it is moved slowly at right angles to the slit, securing a continuous record of the spectrum. The same observations are repeated at the end of totality. The details of the apparatus require, of course, careful consideration.

JAMES E. KEELER.

I think a photographic search for an intramercurial planet, and a study of the brightness of various portions of the sky by means of photography, such as I made in Grenada in 1886 (*H. C. O. Annals*, **18**) would be of value. I do not think that mere pictures of the corona, unless upon a large scale with good definition, will have anything more than a personal interest. . . .

I shall make a study of the brightness of the sky as above described. I should like to make a search for an intramercurial planet. I have already completed a series of photographic observations which show that during an eclipse it is possible to photograph stars as faint as the seventh magnitude. We are at the present time reasonably sure from visual observations that no such planet brighter than the 3.0 or 3.5 magnitude exists, but have no evidence with regard to smaller bodies. My observations show that a body of the size of an average asteroid, say, 20 miles in diameter, located within 15 million miles of the Sun, would certainly show upon my plates. The nearer to the Sun it lies the more conspicuous it would become.

W. H. PICKERING.

In thinking about what the observatories having small incomes might do in connection with the total eclipse of the Sun of May 28, 1900, it has occurred to me that it might be useful to take photographs during totality at various points along the path of the shadow in America and also in Spain and from these possibly obtain definite evidence of change in the corona during the interval. Careful orientation would be necessary. To obtain a zero of position angle a *réseau* or a single line on the plate might be used (possibly a vertical line) and the crescent Sun photographed just before and after totality. A combination of three photographs taken at any given place with the same instrument, one before, one during, and one after totality, ought to fix the position angle of any given coronal ray pretty accurately.

ORMOND STONE.

(*a*) Little has been learned of the details of structure in the corona. A closer examination of special portions under good telescopic power is suggested in addition to photographs. (*b*) Corresponding observations made by observers in this country and in Portgual and Spain can be arranged to advantage in this eclipse on any agreed-upon subject. (*c*) A cloudy weather program, made up, *e. g.*, of meteorological notes, degree of darkness, change of color, change in light by jumps instead of gradually, it is well to arrange for, in case the sky is cloudy.

WINSLOW UPTON.

It is proposed to measure the rate at which the radiating power of the solar atmosphere diminishes with the altitude above the photosphere, and to obtain a rough quantitative comparison with photospheric radiation. The apparatus required is as follows: (1) a large siderostat with a good driving-

clock, and freely moving attachments permitting rapid but fairly accurate adjustment. The plane silvered mirror should be about a foot and a half in diameter. (2) A concave silvered mirror, about one foot in aperture and 30 to 40 feet in focal length, mounted on a tripod with adjusting screws. (3) A linear bolometer (exposed part of strip about 5 mm long by $\frac{1}{4}$ mm wide) in a cylindrical water jacket, the strip being viewed from behind by an eyepiece. The entire bolometer case must be capable of being moved radially in the solar image by a recording, slow-motion screw, the strip being set tangent to the limbs of the Sun and Moon at the point of internal contact by revolution of the case in its holder. The holder preferably slides on a vertical bar with massive tripod base, and adjustments resembling those of a cathetometer. (4) A delicate galvanometer, nearly dead-beat, with time of half-swing three to five seconds, and a wide-range shunt operated by the reader. The shunt may be a resistance box, with coils from $\frac{1}{100}$ to 1000 ohms, the resistance of the galvanometer being about 10 ohms. (5) A bolometer battery suited to the rest of the apparatus.

The reflection from the concave mirror need not return on the path from the siderostat, but may fall upon the bolometer placed in a shelter on one side, where also the galvanometer and battery are situated. The concave mirror and siderostat may have separate shelters.

The screens for exposing may be permanently withdrawn during totality, but the galvanometer's zero-reading must be approximately constant.

Final adjustments, with instruments almost entirely screened, must be made on the vanishing crescent a few minutes before totality.

One observer must be detailed to keep the siderostat accurately pointed to the Sun, *not*, as is commonly done, by the use of a finder attached to some part of the siderostat-movement, and sharing its lost motion, but by means of a telescope with adjustable cross-wires, receiving a portion of the beam from the mirror. A micrometer-reader at the bolometer, recording silently both the setting and the time, a galvanometer-reader, who also manipulates the shunt and calls the galvanometer deflections aloud, an observer at the eyepiece who exposes by withdrawing the screens in the path from the siderostat to the concave mirror, setting the bolometer thread in the coronal image, and calling out "read," a timekeeper and a recorder who has the faculty of doing several things at once, and who records galvanometer readings and times, with any remarks by the observer at the eyepiece, will be needed. The observer at the eyepiece controls the others by his movements, and must give directions and warnings.

Since we cannot tell beforehand what deflections to expect, there must be the ability to alter the sensitiveness of the galvanometer rapidly. Suppose that the first deflection, immediately after totality is announced, is 25 div. (the shunt being 1 ohm). The shunt resistance is at once increased until

a deflection of (let us say) 250 div. is obtained for tangency, or in the brightest part of the corona. The micrometer-reader notes the micrometer setting for the position of tangency at that instant. The bolometer is then moved radially outward by steps, the galvanometer-reader calling successively (*e. g.*, 200, 150, 100, 50, or whatever the readings may be) and the micrometer-reader noting the corresponding positions. Our reading must be made on the Moon during totality to determine atmospheric radiation.

If there is still time, shift 180° (most rapidly effected by the assistant at the siderostat) and repeat the measurements on the opposite side of the Sun, securing, if possible, tangential readings just before emergence.

Final measurements on the photosphere may be made conveniently by following the edge of the Moon, noting times. A variety of stops should be provided for the concave mirror, to be used in addition to the shunt in securing manageable deflections during this stage. I do not allude to the precautions required in bolometric measurement, as this would require a small treatise.

Since there is no present prospect of my securing such an outfit, I can only add that I should be very glad to undertake the work, if opportunity offers.

FRANK W. VERY.

As to the observations to be considered most important, I rather naturally think of spectroscopic, especially in the lower portion of the spectrum, which thus far has been only very imperfectly reached by photography. The questions as to changes in the "flash-spectrum" from second to second, and, in view of Mr. Lockyer's recent paper in *Nature*, and Mr. Campbell's observations of the eclipse of 1898, the verification or otherwise of their result for the wave-length of the coronal line. Photographic and visual observations should be combined, and both "analyzing" and "integrating" spectroscopes. I leave to others problems relating to photometry and polarization.

C. A. YOUNG.

By vote of the conference the committee was continued. Intending observers of the eclipse are requested to communicate with the committee regarding their plans of work.

The committee on the United States Naval Observatory, appointed at the Harvard Conference, reported that the opinions of astronomers regarding the organization of the Naval Observatory had been obtained and communicated to the Secretary of the Navy. In harmony with the suggestion of the committee, the Secretary of the Navy, with the advice and approval of the Superintendent of the Observatory, has appointed a Board of Visitors to visit, examine and report upon the United States

Naval Observatory. This board, which consists of Hon. William E. Chandler, chairman; Professor George C. Comstock, secretary; Hon. A. G. Dayton, Professor E. C. Pickering, and Professor George E. Hale, visited the Observatory on June 30, 1899, and will meet again in Washington on September 26 to complete its report.

As the third conference, like the two preceding ones, was well attended by representative astronomers and astrophysicists from all parts of the country, it seems safe to assume that these annual meetings are serving a useful purpose, and that the permanent organization now established will continue to advance the interests of astronomy and astrophysics. G. E. H.

PRELIMINARY REPORT FROM THE OBSERVATIONS OF 1899 TAKEN TO SURVEY THE CLOUD CONDITIONS OF THE ECLIPSE TRACK OF 1900.

By Frank H. Bigelow.

During the intervals of time, May 15 to June 15 inclusive, for each of the years 1897, 1898, 1899, respectively, series of observations were made on the state of the sky in general and near the Sun, at the morning hour 8 A. M. to 9 A. M., to discover the probable meteorological conditions likely to prevail at the different parts of the eclipse track of May 28, 1900. These observations were all made in exactly the same way, usually by the same observers in the several years, and recorded on a simple scale from which the percentage of cloudiness actually noted could be easily computed. As the final result of the three years' observations is alone of special interest to astronomers, who are engaged in locating eclipse parties for that occasion, this will be found in the accompanying table.

RESULT OF THE THREE YEARS' OBSERVATIONS FOR CLOUDINESS ALONG THE ECLIPSE TRACK, MAY 28, 1900.

States	1897	1898	1899	Means
Virginia	... ...	44.9 41.7	35.7 34.3	40.3 38.0
North Carolina	35.8 33.3	28.2 25.7	33.3 30.6	32.4 29.9
South Carolina	33.7 32.1	17.5 16.0	28.1 26.7	26.4 24.9
Georgia	18.4 16.0	12.2 10.8	18.5 17.4	16.4 14.7
Alabama	15.2 14.9	17.1 15.7	22.4 22.6	18.2 17.7
Mississipi	... ...	23.0 26.4	38.6 31.9	30.8 29.2
Louisiana	26.5 21.5	36.4 30.9	35.9 30.6	32.9 27.7

The first column of figures under each year gives the mean percentage of cloudiness for the entire month of observation for the sky in general, as seen by the observer; the second column gives the mean percentage in the immediate vicinity of the Sun. The last section gives the means of the three years. Two facts are very evident as the result of these observations: (1) The three years each give the same result and therefore this must be founded upon a definite meteorological phenomenon pertaining to that region and season of the year. (2) The general fact is that the eclipse track region in the states of Georgia and Alabama is decidedly less cloudy than in the other states which are nearer the ocean areas, and which lie at lower levels. The conclusion follows that the chances of fair weather are better for eclipse parties locating on the highland of the southern portions of the Appalachian Mountains than in the lower districts nearer the Atlantic Ocean and the Gulf of Mexico. Of course this mean result is no guarantee that such local cyclonic conditions will not prevail on the morning of May 28, 1900, as to entirely modify this calculation, but the indications are that it will be at least twice as safe to locate there, as near the coast line.

A more complete report is soon to be issued by the Weather Bureau, which will contain other useful information for eclipse observers, such as the approximate longitude, latitude, altitude, hotel accommodations, drift of smoke, and easily accessible heights, for the towns which are located quite near the central line of the eclipse track. It will also contain a map of the southern states, with the boundaries of the eclipse track marked upon it, the location of the towns, the topography, and the available railway transportation lines.

U. S. Weather Bureau,
Washington, D. C.

THE NOVEMBER METEORS OF 1899.[1]

The predicted time of maximum of the November meteors is November 15, 1899, at 18^h Greenwich Mean Time. As a similar shower may not occur again for thirty years, no pains should be spared to secure the best possible observations. The most useful observations that can be made by amateurs are those which will serve to determine the number of meteors visible per hour throughout the

[1] *Harvard College Observatory Circular* No. 45.

entire duration of the shower. *Circular* No. 31 was accordingly distributed last year, and numerous valuable observations were thus secured from observers in all parts of the world. The results, some of which are given below, are now being discussed by Professor W. H. Pickering, and will be published later in the *Annals*. Similar observations are desired this year, and it is hoped that they may be made on November 15, and also on the two preceding and following evenings. The most important time for observation is from midnight until dawn, as comparatively few meteors are expected earlier. Observations are particularly needed at hours when they cannot be made at the observatories of Europe and America. In general, the time required for ten or more meteors to appear in the region covered by the accompanying map, should be recorded. This observation should be repeated every hour or half hour. If the meteors are too numerous to count all those appearing upon the map, the observer should confine his attention exclusively to some small region such as that included between the stars μ Ursae Majoris, 40 Lyncis, δ and α Leonis. If the meteors occur but seldom, one every five minutes, for instance, the time and class of each meteor should be recorded. Also, note the time during which the sky was watched and no meteors seen, and the time during which that portion of the sky was obscured by clouds. Passing clouds or haze, during the time of observation, should also be recorded. The date should be the astronomical day, beginning at noon, that is, the date of early morning observations should be that of the preceding evening. Specify what time is used, as Greenwich, Standard, or Local Time. When a meteor bursts, make a second observation of its light and color, and when it leaves a trail, record the motion of the latter by charting the neighboring stars, and sketching its position among them at short intervals until it disappears, noting the time of each observation. If the path of a meteor is surely curved, record it carefully upon the map.

On November 14, 1898, thirty-four photographs were obtained of eleven different meteors. Their discussion has led to results of unexpected value. The greatest number of meteors photographed by one instrument was five. Only two meteors were photographed which passed outside of the region covered by the map, although the total region covered was three or four times as great. No meteors fainter than the second magnitude were photographed.

Photographs may be taken, first, by leaving the camera at rest,

when the images of the stars will trail over the plate and appear as lines, or secondly, attaching the camera to an equatorial telescope moved by clockwork, when a chart of the sky will be formed in which the stars will appear as points. A rapid-rectilinear lens is to be preferred in the first case, a wide-angle lens in the second. The full aperture should be used, and as large a plate as can be covered. The most rapid plates are best for this work ; they should be changed once an hour, and the exact times of starting and stopping recorded. Care should be taken to stiffen the camera by braces, so that the focus will not be changed when the instrument is pointed to different portions of the sky, especially if the lens is heavy. If the first method is employed, the position of the camera should be changed after each plate, so as to include as much as possible of the region of the map on each photograph. If pointed a little southeast of ϵ Leonis, the radiant will reach the center of the field about the middle of the exposure. A watch of the region should also be kept, and the exact time of appearance and path of each meteor as bright as the Pole Star should be recorded. The plates should be numbered on the film side with a pencil, and should be sent to this Observatory with accompanying notes and other observations. After measurement here, they will be returned if desired. The value of the results will be much increased if similar photographs can be obtained by a second camera from ten to forty miles distant, and preferably north or south of the other.

EDWARD C. PICKERING.

September 1899.

A LONG PHOTOGRAPHIC TELESCOPE.

LAST spring a plan was proposed at the Harvard College Observatory for the construction of a telescope of unusual length for photographing the stars and planets. Anonymous donors have now furnished the means by which this experiment may be tried. The plan will, therefore, take definite shape, and it is expected that a telescope having an aperture of twelve inches and a length of a hundred feet or more will be ready for trial at Cambridge in a few weeks.

EDWARD C. PICKERING.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

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